EXPOSED

ANNUAL REPORT 2017

CONTENT

Centre host:
SINTEF Ocean
Postboks 4762 Torgarden
7465 Trondheim, Norway

Contact:
Centre Director
Hans V. Bjelland
hans.bjelland@sintef.no
(+47) 98829872

EXPOSED AQUACULTURE OPERATIONS
CENTRE FOR RESEARCH-BASED INNOVATION
exposedaquaculture.no

SUMMARY

*In 2017, several innovations and new fish farming concepts have been presented, driven by the opportunity to apply for **development licences** and the persistent challenges of sea lice. Many of the 104 submitted applications aim at **farming at exposed locations**.*

*SalMar's **Ocean Farm 1** was the first concept to be approved. Partners in EXPOSED contribute with significant R & D to this and several of the other novel fish farm concepts.*

*Also, fish farming and marine operations at **current sites** with state-of-the-art technology **remain challenging** and are still highly relevant for the research within the EXPOSED centre.*

EXPOSED is a Centre for Research based Innovation (SFI) and is funded by the Norwegian Research Council's Division for Innovation[1]. An SFI has a main objective to enhance the capability of the business sector to innovate by focusing on long-term research through creating close alliances between research-intensive enterprises and prominent research groups. The EXPOSED Centre brings together global salmon farmers, key service and technology providers, and leading research groups to develop knowledge and technology for robust, safe and efficient fish farming at exposed locations.

With its broad and competent consortium of partners, the EXPOSED centre is well positioned to identify challenges and limitations to current fish farming operations, as well as to identify knowledge gaps related to new farm concepts. Through projects and other activities, relevant solutions are being explored.

Efficient governance and regulation of the industry will be important to fulfil the ambitions of EXPOSED. With its broad scope, the centre is expected to provide knowledge and input that will be highly valuable to future revisions of the regulatory framework. The centre management and the EXPOSED partners are in active dialogue with the authorities, contribute to the revisions of technical standards and have developed new classification rules for offshore fish farm units.

At present, there is a strong innovation drive in the aquaculture industry, and extensive investments are done. The centre and its partners are valued contributors to this development, through their role as partners in R&D projects, in scientific and industrial fora, and in the public debate.

sfi Centre for Research-based Innovation
The Research Council of Norway

[1] http://www.forskningsradet.no/prognett-sfi/Forside/1224067021121

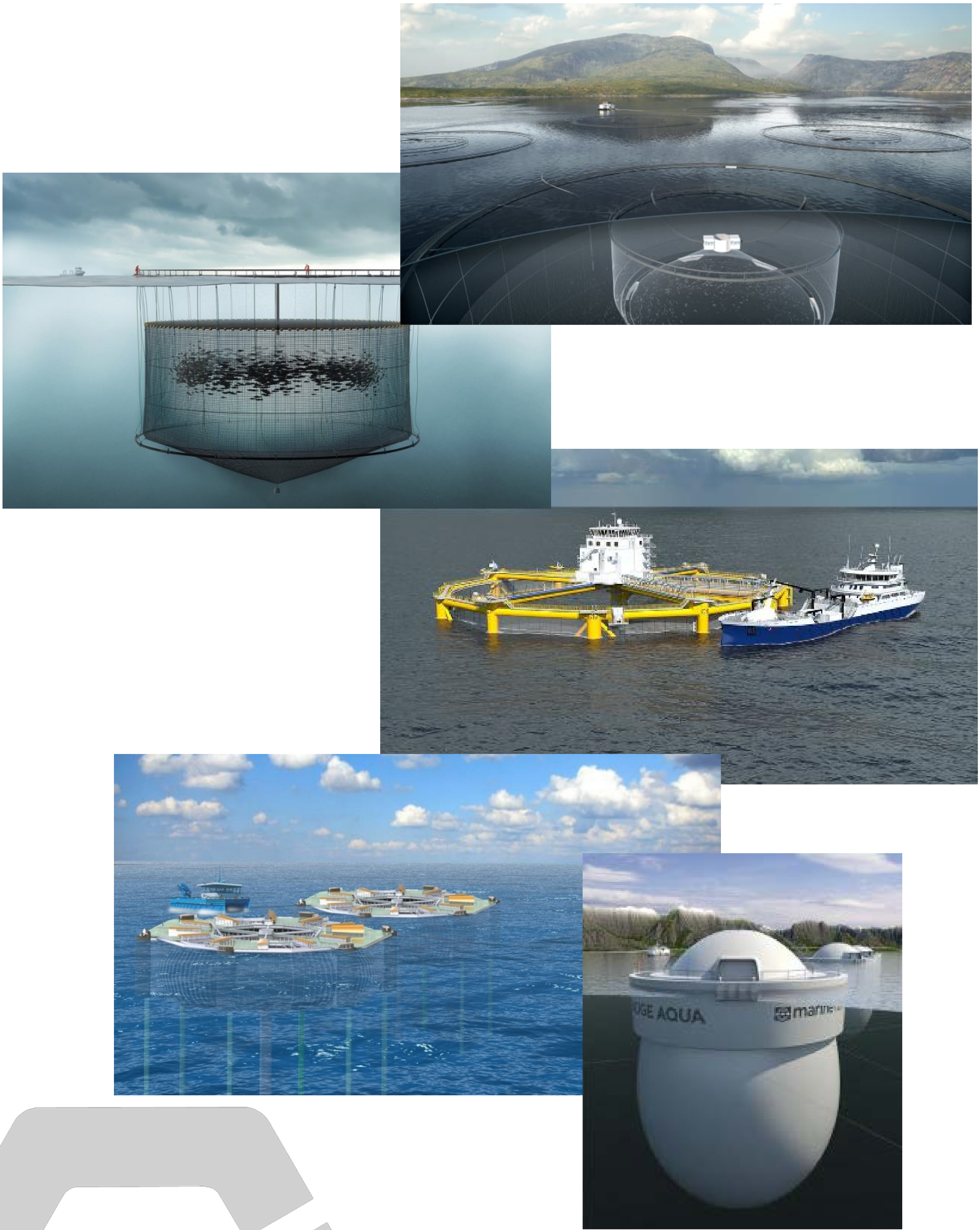


Figure 1 New concepts for aquaculture farming that our partners are developing. This is, Cermaq's "iFarm", Aqualine's "Subsea System", SalMar's "Ocean Farm 1" and Marine Harvest's "Marine Donut" and "Egget".

VISION AND OBJECTIVES

*EXPOSED will develop knowledge and technology for **robust**, **safe** and **efficient** fish farming at exposed locations.*

Significant parts of the Norwegian coast are today unavailable to industrial fish farming due to remoteness and exposure to harsh wind, wave and current conditions. The EXPOSED aquaculture operations Centre will take advantage of Norway's strong position in the aquaculture, maritime and offshore sectors to enable safe and sustainable seafood production in exposed coastal and ocean areas. Technological innovations, such as more autonomous systems, offshore structures and vessels are needed to sustain farm production under all conditions and enable more robust, safe, controlled and continuous operations.

Main objective

To develop knowledge and technologies for EXPOSED aquaculture operations, enabling a sustainable expansion of the fish farming industry.

Industry objectives

- Enable safe and profitable operations at exposed fish farming sites to increase sustainable seafood production.
- Develop new technologies to underpin Norway's global leading position in aquaculture and maritime competence and technology.

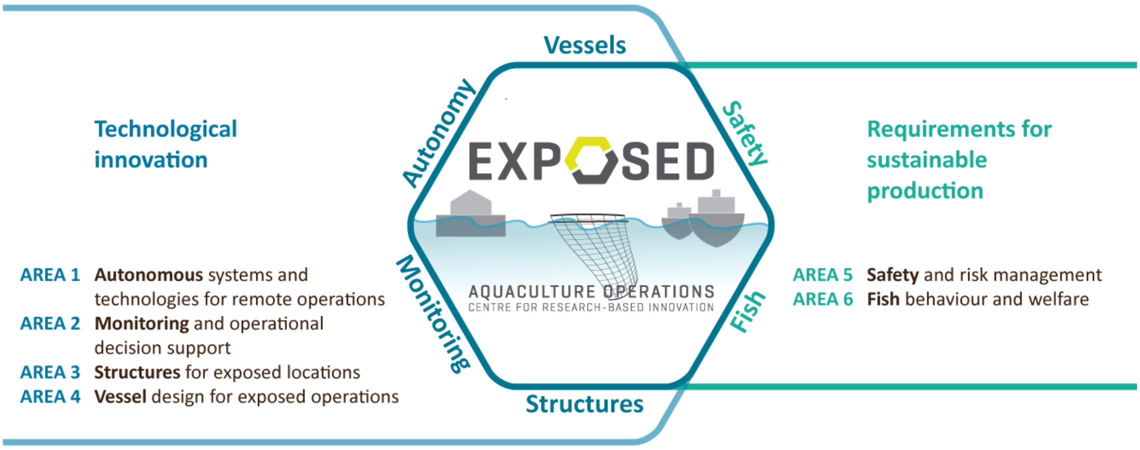
Research objectives

- Conduct fundamental and applied research into key knowledge gaps related to exposed aquaculture operations by combining research fields from the aquaculture, maritime and offshore sectors.
- Build knowledge and competence capacity through educating at least 11 PhD candidates, 4 post-docs and 30 MSc candidates.

EXPOSED brings together global leading salmon farmers, key service and technology providers, and leading research groups as SINTEF, the Institute of Marine Research and the Norwegian University of Science and Technology, including AMOS (the Norwegian Centre of Excellence for Autonomous Marine Operations and Systems).

RESEARCH STRATEGY AND PLAN

EXPOSED has identified six core ***research areas*** *to address the challenges described.*



Four of these focus on technological innovations for safe and reliable aquaculture operations:

- Area 1: Autonomous systems and technologies for remote operations
  Daily routine work and periodical operations must become less dependent on close human intervention.

- Area 2: Monitoring and operational decision support
  Severe weather conditions and remoteness impede access and increase the need for robust monitoring of structures, systems and fish welfare to assess system state and support operational decisions.

- Area 3: Structures for exposed locations
  Aquaculture structures need to be operational at exposed sites with respect to sea load response, personnel safety and fish welfare. Flexible and rigid systems, active regulation, and new concepts will be studied.

- Area 4: Vessel design for exposed operations
  Vessels, on-board equipment and logistical solutions must be designed to enable safe and efficient operations in exposed areas.

Two research areas focus on key requirements for sustainable production:

- Area 5: Safety and risk management
  Exposed operations require improved risk management strategies and systems.

- Area 6: Fish behaviour and welfare
  The technologies and new operational solutions must ensure fish performance and welfare in exposed condition.

*Activities in EXPOSED are organised in **projects**, combining research areas, partners and methods.*

Nine projects (P2 – P10) were active in 2017, covering fundamental research, applied studies, innovation activities, establishment of research infrastructure, and six PhD candidates. In addition, several associated projects carry out relevant research activities and involve supplementary candidates. Two new projects, P9 and P10 started in 2017. The projects are presented in more detail under *Scientific activities and results* (p. 16).

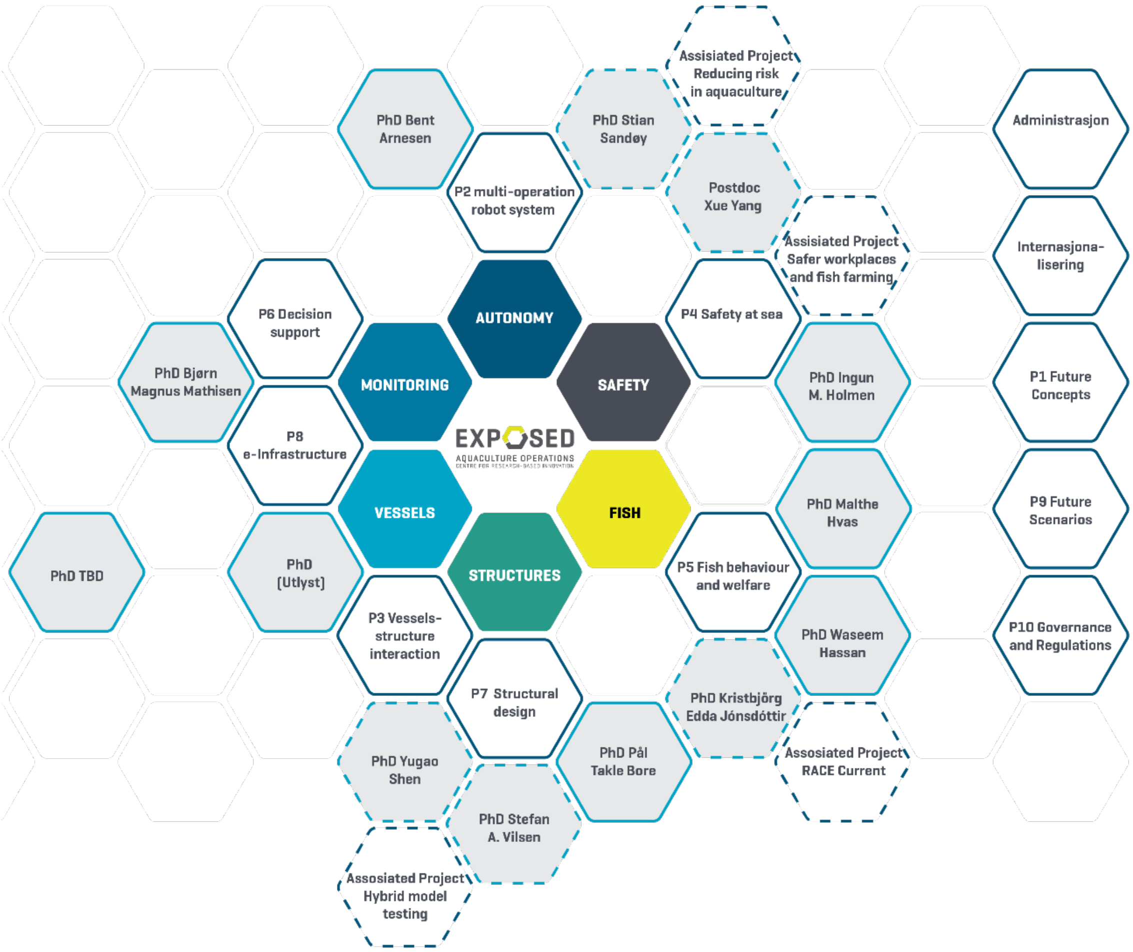


Figure 2 Activities will be organised in projects, combining research areas, partners and methods. PhDs and postdocs will take part in the project teams. A selection of associated projects and PhDs are indicated with dashed strokes.

To further support research and innovation, the EXPOSED centre aims to initiate or encourage ***associated projects****, in addition to the centre-funded projects.*

Associated projects typically involve one or more of the centre partners, and potentially others. They may vary between researcher based projects (e.g. funded by the Norwegian Research Council or EU) or more innovation-driven projects. The centre will seek to establish agreements with these projects to allow mutual benefits and synergies between EXPOSED and associated projects.

There is also an identified potential in collaboration with other research centres and groups. EXPOSED already has common activities and shared PhD-students with NTNU AMOS (the Norwegian Centre of Excellence for Autonomous Marine Operations and Systems). EXPOSED currently collaborates with NTNU AMOS and the two other maritime centres for research based innovation, SFI Move (Centre for research and innovation for demanding marine operations) and SFI Smart Maritime (Centre for improved energy efficiency and reduced harmful emissions from the maritime sector) on PhD-training. There are also potential for future collaboration with SFI CtrlAqua (Centre of Research-based Innovation in Closed-Containment Aquaculture).

A selection of associated projects is listed below. Some of these will also be presented along with the results under *Scientific activities and results* (p. 16).

Figure 3 Photo by Marius Dahle Olsen

Associated projects	Duration, project type and funding source	Host institution	Relevant EXPOSED-activity
Reducing risk in aquaculture – improving operational efficiency, safety and sustainability	2016-2019 Research based in HAVBRUK2	NTNU Department of Marine Technology	Project P2 and P4 See updates (p. 18)
Safer operations and workplaces in fish farming	2016-2018 Research based in HAVBRUK2	SINTEF Ocean	Project P4 See updates (p. 24)
SEATONOMY	2013-2016 (finished) Strategic research project of the SINTEF Group	SINTEF Digital	Project P2
RACE Current – Farm scale currents, in and between cages	2015-2018 Strategic research project of the SINTEF Ocean	SINTEF Ocean	Project P5 and P7
BEHAVEGENES - Behavioural and genomic characteristics of selected farmed salmon families related to robustness, welfare and performance	2014-2017 Research based in HAVBRUK	Institute of Marine Research	Project P5
ECHOFEEDING - Echo sounder technology for appetite-led-feeding and welfare-monitoring of caged salmon	2017-2020 Research based in HAVBRUK2	Institute of Marine Research	Project P5 See updates (p. 29)
Furturewelfare - Environmental requirements and welfare indicators for new cage farming locations and systems	2017-2021 Research based in HAVBRUK	SINTEF Ocean	Project P5 See updates (p. 29)
LAKSIT - Technologies for new datatypes and information describing the states of salmonids in commercial cages	2016-2017 The Norwegian Seafood Research Fund FHF	SINTEF Ocean	Project P5
HYBRID - Real-time hybrid model testing for extreme marine environments	2016-2019 Knowledge-Building Project for Industry in MAROFF	SINTEF Ocean	Project P3 and P7 See PhD-profile (p. 39)
SalmonInsight - Unveiling links between salmon physiology and online monitored behaviour	2018-2022 Research based in HAVBRUK2	SINTEF Ocean	Project P5
Industriell forskning på fartøysbaserte operasjoner for eksponert havbruk	2018-2020 Innovation project in MAROFF	Lerow	Project P3 and P7 See innovations (p. 14)

SMART MARITIME

MOVE SFI Marine Operations

AMOS

ORGANISATION

Organisational structure

Organisation and implementation of the centre are governed by a **consortium agreement**, describing the obligations and rights of the partners, as well as roles and responsibilities of the different parts of the organisation. The **General Assembly**, with representation from all partners, elects the **Centre Board** of seven members among the centre partners. The board is the operative decision-making body for the execution of the centre. In 2017, the following people where members of the board:

Member of Centre Board	Affiliation
Arne Rinnan (Chairman)	Kongsberg Seatex
Noralf Rønningen	Aqualine
Bjørn Egil Asbjørnslett	NTNU
Arne Fredheim	SINTEF Ocean
Olai Einen	Cermaq
Stein Are Ystmark	AQS
Frode Oppedal	Institute of Marine Research
Kjell Emil Naas (Observer)	The Research Council of Norway

Figure 4 EXPOSED Days in May 2017.

The **Centre Director**, Hans Bjelland manages the Centre on behalf of the Host institution, SINTEF Ocean, and reports to the Centre Board. Together with the **Management Group**, the Centre Director manages centre activities related to **projects**, **education** and **innovation**. The Management Group consists of Research Managers for the six core research areas, Project Managers, and a NTNU representative:

Member of Management Group	Role and responsibility
Hans V. Bjelland SINTEF Ocean	Centre Director Project P1, P9 and P10
Esten Ingar Grøtli SINTEF Digital	Area 1 Project P2
David Kristiansen SINTEF Ocean	Area 3 Project P7
Ørjan Selvik SINTEF Ocean	Area 4 Project P3
Ingunn M. Holmen SINTEF Ocean	Area 5 Project P4
Ole Folkedal Institute of Marine Research	Area 6 Project P5
Gunnar Senneset SINTEF Ocean	Area 2 Project P6 and P8
Leif Magne Sunde SINTEF Ocean	Aquaculture operations
Ingrid Schjølberg NTNU	NTNU representative

Projects are set up with a **Project Manager** and a **Steering Committee**. The project leader has the responsibility for carrying out the project, while the Steering Committee has the responsibility to follow up on the progress and objectives. The Steering Committee is managed by one of the industrial partners.

Education is primarily maintained through the three NTNU departments, Marine Technology, Computer and Information Science, and Engineering Cybernetics. In addition, PhD and MSc candidates are educated at the University of Bergen through a collaboration with the Institute of Marine Research. PhD and post.doc candidates are associated with related projects. Several other NTNU departments have been involved in MSc and Bachelor student activities related to the centre.

Innovation is supported through arranging a yearly two-day EXPOSED Day during spring, a one-day EXPOSED Day during autumn, and two yearly PhD/post-doc workshops. The EXPOSED Days serve as a meeting place for innovation, presentation of results, exchange of ideas and creation of new projects. Further partner involvement and cross-disciplinary interaction takes place in the individual projects.

The centre host, SINTEF Ocean, is located in Trondheim, and serves as a centre hub for centre activities. Other activities are carried out elsewhere in Trondheim and other parts of Norway, where partners and field activities are located.

Research facilities

The centre has access to an extensive research infrastructure through its research partners:

- A full-scale Aquaculture Engineering test site (SINTEF ACE) at SalMar locations in Mid-Norway and exposed Marine Harvest and Cermaq locations in West and North Norway for both technological and biological studies. Technical e-infrastructure integrating the SINTEF ACE aquaculture research sites with SINTEF Sealab SSO, enables secure access for project partners.
- Ocean Basin (80 x 50 x 10 m), Ship Towing Tank (260 x 10.5 m), Marine Cybernetics Laboratory (40 x 6.45 x 1.5 m) and Marine structures laboratory at SINTEF Ocean/NTNU.
- Flume tank (21 x 8 m) at SINTEF Ocean
- Applied Underwater Robotics Laboratory (ROVs and AUV), RV Gunnerus and Unmanned Aerial Vehicles Laboratory at NTNU.
- IMR experimental farms at Solheim and Austevoll and at IMR's land-based facilities in Matre to conduct scaled-down biological trials.
- Extensive hydrodynamic and structural testing laboratories through international partners.

Figure 5 Full-scale testing at SINTEF Aquaculture Engineering test site, Tristeinen

Partners

EXPOSED brings together global leading salmon farmers, key service and technology providers, and leading research groups.

	Industry partners	Contribution/Role
marineharvest	**Marine Harvest** World's largest salmon and trout fish farmer. Runs large operations in Norway, Scotland, Canada and Chile.	End user of technology and solutions
cermaq	**Cermaq** World's third largest salmon and trout fish farmer with operations in harsh environments especially in the northern parts of Norway.	End user of technology and solutions
SALMAR	**SalMar** World's fourth largest salmon and trout fish farmer. Operates large fish farms in particular at exposed locations in mid Norway.	End user of technology and solutions
KONGSBERG	**Kongsberg Seatex**, **Kongsberg Maritime Subsea** and **Kongsberg Maritime** Supplier of technology and systems to the global maritime and offshore sector. Provides knowledge of and systems for communication, control, navigation, decision support, AUV etc.	Technology/solution provider
aqualine	**Aqualine** Major international supplier of equipment and complete fish farms.	Technology/solution provider
møre maritime	**Møre Maritime** Provides maritime consulting, engineering and 3D modelling.	Technology/solution provider
	ÅF A leading engineering and design company within the fields of energy, industry, infrastructure and digital solutions. ÅF Engineering focus on engineering customized robust and sustainable solutions, both on land and in sea. Our customers are from a variety of sectors, including aquaculture.	Technology/solution provider
Anteo	**Anteo** Operates and develops technical solutions and decision support systems for fish farming companies.	Technology/solution provider
ARGUS	**Argus Remote Systems** Performs research, development and manufacturer of electrical ROVs.	Technology/solution provider
LERØW AS	**Lerow** Service provider for inspection and cleaning of net cages and moorings by advanced use of ROV.	Service provider
AQS	**AQS** Service provider for inspection, maintenance and a range of operations, including delousing.	Service provider
marin design as	**Marin Design** Provides vessel design and maritime consulting.	Technology/solution provider
DNV·GL	**DNV GL** is a leading classification society and certification body, and a recognized advisor to a wide range of industries.	Certification, classification and advisory
MACGREGOR	**MacGregor Norway** A maritime leading provider of solutions and services for handling systems to the offshore, fishery, research and mooring segments.	Technology/solution provider

Selected innovations among partners

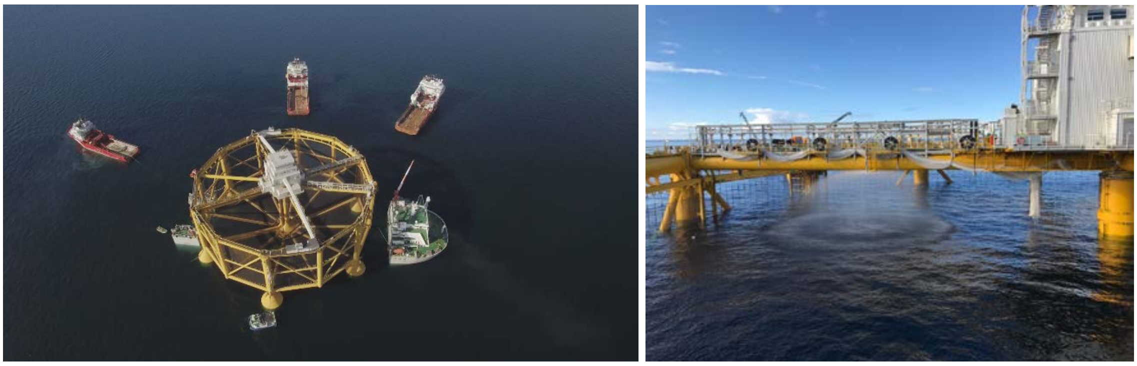


Figure 6 Ocean Farm 1 – the first development license farm concept accepted and deployed – has now arrived at Frohavet.

SalMar has developed Ocean Farm 1 in collaboration with partners within and outside of EXPOSED. Ocean Farm 1 is a full-scale pilot facility, and is designed to test out both the biological as well as the technological aspects of offshore fish farming. **Kongsberg Maritime** is responsible for electrical installations and instrumentation for marine and fish handling systems, **SINTEF** has been working on model testing and associated analysis, and with environmental data and calculation of currents. **DNV GL** has conducted a third-party verification and certification of the system.

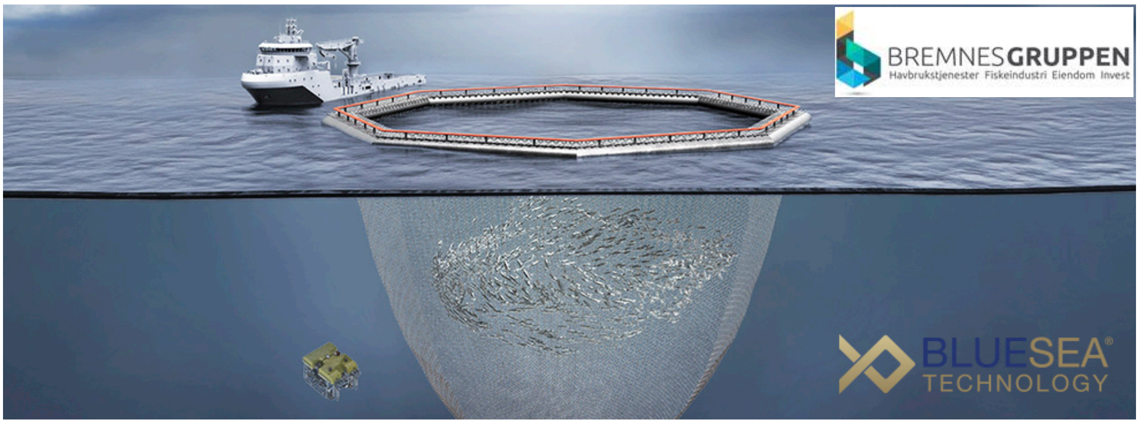


Figure 7 The BlueSea Concept: A brass made net from Lerow.

Lerow is developing reliable and robust solutions for vessel based operations. The aim is to develop innovative technology that is suitable for exposed farming regardless of the weather conditions. These innovations include ROV, autonomous systems, robotics, and vessels that will be used as platforms for inspection, monitoring, maintenance, repair and fish handling on exposed fish farms. In addition, Lerow is developing the "BlueSea" concept, involving a brass net to that is intended to be more escape proof, requires little maintenance and has a natural resistance against algae growth.

Aqualine is using SINTEF's research facilities as a part of their product development before they test new concepts in full scale. This gives Aqualine valuable knowledge and experience about their concepts so they can improve them as many times as needed before the products are launched to the marked. Examples of products that have utilised this in product development are the company's "Midgard system" and its feed hoses.

Figure 8 A new type of well boat made by Møre Maritime

Møre Maritime is developing several new vessel concepts that can be used in exposed farming. One range of concepts are for a new type of well boat that differ in size between 2500 m^3-4500 m^3. In addition, Møre Maritime is working on new concepts for a combination of a well- and slaughter boats. Another innovation recently introduced is antiroll tanks for service boats. With this type of tank on board, the service boats are better suited for work at exposed locations.

Research partners

	AREA
SINTEF Ocean (SO) SINTEF Ocean conducts research and innovation related to the ocean space for national and international industries. Our ambition is to continue Norway's leading position in marine technology and biomarine research.	All
SINTEF Digital [SD] provides research-based expertise, services and products ranging from robotics, microtechnology, communication and software technology, computational software, information systems and security and safety.	1, 2
NTNU Department of Marine Technology (IMT) The department carries out research within the field of marine technology, and is the largest in its field in the western world. IMT hosts the Centre for Autonomous Marine Operations and Systems (AMOS), a Norwegian Centre of Excellence. AMOS will have a key role within the EXPOSED centre.	1, 3, 4, 5
NTNU Department of Computer and Information Science (IDI) The department conducts research in fields of computer and information science, covering hardware related research, intelligent systems and social implications of information systems.	1, 2
NTNU Department of Engineering Cybernetics (ITK) The department conducts research on various fields associated with control theory, including mathematical modelling and simulation, autonomy, optimisation and automatic control. Together with IMT, ITK plays a major role in the Centre for Autonomous Marine Operations and Systems (AMOS).	1, 2, 6
The Institute of Marine Research (IMR) is Norway's largest centre of marine science. The main task is to provide advice to Norwegian authorities on aquaculture and the ecosystems.	6

SINTEF   NTNU Norwegian University of Science and Technology   HAVFORSKNINGSINSTITUTTET INSTITUTE OF MARINE RESEARCH   AMOS

SCIENTIFIC ACTIVITIES AND RESULTS

Nine projects have been carried out in 2017, covering fundamental research, applied studies, innovation activities, establishment of research infrastructure, and six PhD candidates.

P2 In-cage multi-operation robot system for inspection and intervention

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
Esten I Grøtli, SD	**SINTEF Ocean, SINTEF Digital, NTNU IMT, Argus, Lerow, Kongsberg Maritime Subsea, Kongsberg Seatex, AQS, Marine Design, Møre Maritime**	**Q2 2015 – Q4 2018**	**Industrial**

This project aims to develop and demonstrate technologies for an underwater vehicle fitted with various tools to perform frequent operations at exposed sites, including cage integrity inspection and net cleaning.

A frequent and complete inspection of nets in fish-cages is an important task in aquaculture installations today, and will likely be more important when bringing fish farms to more exposed locations due to increased environmental stress on the structure (e.g. wind, waves and currents).

Inspection ensures integrity of the cage, and thus prevent fish escaping, but quickly becomes very expensive for fish farms when performed manually using divers or ROVs (Remote Operated Vehicles). In addition, for a human this inspection task is tedious and boring, thus reducing the necessary attention for finding weaknesses and failures in the net. Therefore, an automation -- or at a first stage a semi automation -- of this task could help to reduce costs and provide an attentional mechanism for a remote operator that can indicate where to focus on possible net-failures in an inspection video stream.

Within this activity SINTEF Ocean and SINTEF Digital worked together on the development and improvement of algorithms that have the potential to be used for autonomous inspections of fish-cage nets for finding net holes. Both a model and a data-driven approach has been used. The former one exploits the knowledge about the basic geometry of the net-structure and the second one conceptually learns from a large amount of video data what an intact net is and can indicate when an unusual or broken net appears in a video stream.

Model driven hole detection

The model driven approach exploits image processing and computer vision techniques to identify candidate locations that may represent the knots and/or the holes of a regular net-structure. Then a check is performed which evaluates if the locally found net structure is consistent with the model of the net and if it also fits consistently into the observed neighbourhood. The advantage of such an approach lies in the fact that it does not need many training data. However, it is necessary to adopt the approach to different lighting conditions (the net may appear bright or dark!) and the video streams should be of reasonable quality (i.e. the mesh should be visible, not too

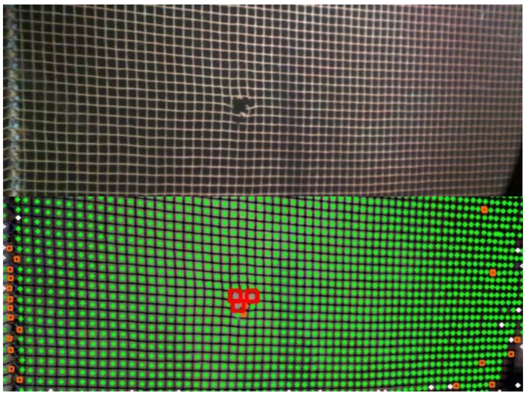


Figure 9 Top image: A single frame from a net-cage inspection video. Bottom image: Analysis results: The red rectangles indicate a potential hole

much motion blur). Seaweed covering an area larger than a single net mesh is currently detected as a deviation from the regular net structure and therefore indicated as possible hole. However, an additional algorithmic check (learning the appearance and determining seaweed in the video) may be used to re-confirm that such areas can be considered as intact net-structure. The image-frames (Figure 9) illustrate the dentification of a hole within an inspection video of a net-cage.

Data driven net structure deviation detection

One of the fundamental breakthroughs in deep learning is that neural networks can be designed with ability to learn from data how to describe an image using small building blocks, referred to as features. These features are trained only from data, removing any user assumptions from the analysis. Given enough data, a network will learn the features needed to solve the task at hand. (For example, a network tasked with detecting faces will learn features that vaguely resembles noses, eyes and mouths, as well as how these are combined in order to comprise a face, very much alike how a human would label something as face or face-like)

Building on these ideas, coupled with the availability of several video streams of non-damaged nets with varying degrees of interference and noise (fouling, fish occluding etc) and with variable illumination, the research focused on using these data driven features to describe videos. A statistical model of what can be viewed as normal nets can be built by accumulating the use of these features, and thus deviations from this model is non-normal pixels in the images. The result is that repeated patterns are observed as normal, where net-structures such as ropes are flagged as deviation. These deviations can then be forwarded to a classifier (network) trained to differentiate these deviations into semantic categories such as net structure, occluding fish, holes etc.

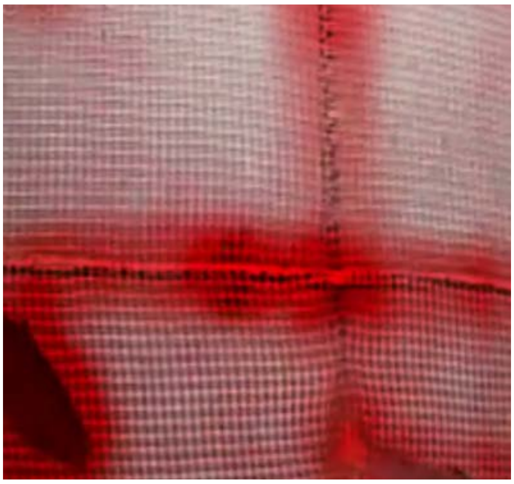


Figure 10 "Repeated patterns are observed as normal, where net-structures such as ropes are flagged as deviation (deep red).

Net-relative localization

For net integrity inspection operations using ROVs, it is very important to be able to accurately decide the position and orientation of the ROV within the net-cage. This information can for instance be used to avoid collision with the net and avoid entanglement of the tether; to accurately pin-point where in the net a hole was detected by the vision system; to know what part of the net has already been inspected; and to plan the motion of the ROV in order to cover the rest of the net structure. Our solution for net-relative localization is based on onboard sensors only (yaw gyro, yaw compass, depth sensor, doppler velocity log, camera, Global Navigation Satellite System (e.g. GPS), and inclinometer or accelerometer. By using a kinematic model of the ROVs position and orientation relative to the net, combined with information from all these sensors, we have obtained very promising results in simulations. The next step will be to use real sensor data in the algorithm, and verify the localization performance against other solutions (e.g. a solution using external beacons for position and orientation).

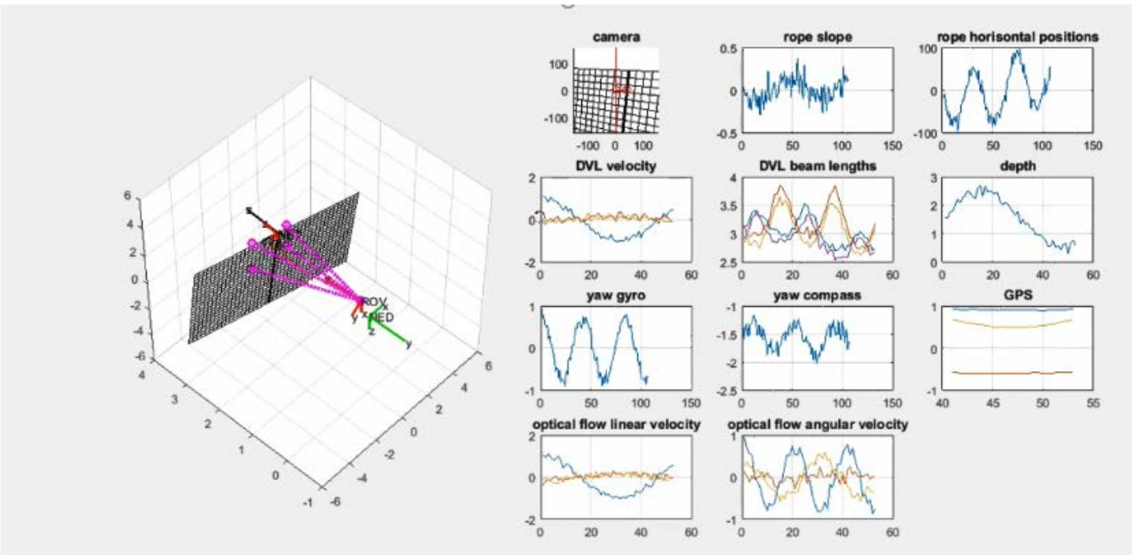


Figure 11 Information from several onboard sensors are fused to estimate the ROVs position and orientation within the net-cage.

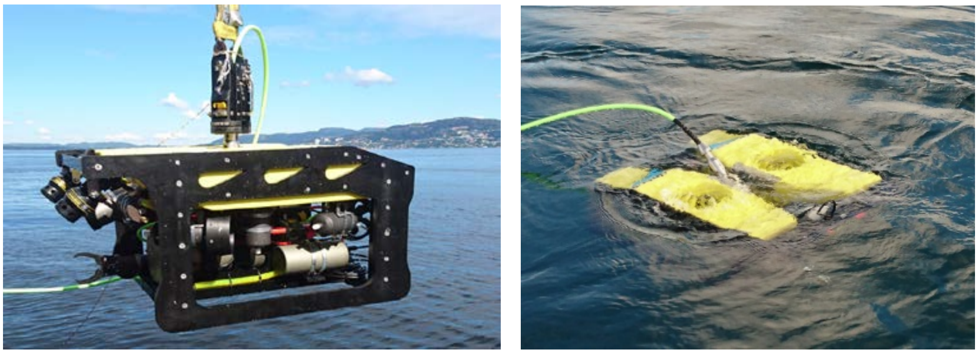


Figure 12 The Argus Mini provided by Argus Remote Systems were used to collect data.

Reducing Risk in Aquaculture (associated project)

This project researches and develops novel concepts for autonomous operations and technology to improve safety and efficiency in aquaculture. In particular, the project will address daily operations and inspection, maintenance, and repair (IMR) for exposed locations, but the project results will also be applicable to more sheltered fish production. Moreover, the project will assess, utilize and possibly adapt technology developed for subsea IMR in the oil and gas industry. Advances in sensor technology, robotics, ICT, and localization methods create new opportunities for reducing operators' manual workload and exposure time on the facilities at sea, for preventing fish escape, and for improving safety and operational efficiency.

Current technologies and operations in fish farms are highly dependent on manual labour for cleaning and maintenance, which leads to close human interactions with tools and fish cage structures. The sea-based aquaculture industry is one of the most dangerous occupations in Norway. Moving fish farms into more exposed areas will lead to increased challenges related to the working environment and management of operations. Hence, technological innovation and autonomy are important for future industry expansion. To ensure that the new concepts reduce risk to people and the environment, adequate risk management becomes even more important for sustainable fish farming operations in the future.

This project has coordinated activities with both P2 and P4 (Safety and risk management).

Reducing Risk in Aquaculture

2016-2019: Research based in HAVBRUK2

Host and partners: **NTNU**, SINTEF Ocean

Project manager: Ingrid Bouwer Utne, NTNU

P3 Vessels-Structures Interaction

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
Ørjan Selvik, SO	**SINTEF Ocean, NTNU IMT, Møre Maritime, Marin Design, AQS, Aqualine, Kongsberg Seatex, Kongsberg Maritime, Cermaq, MacGregor, DNV GL**	**Q2 2015 – Q4 2018**	**Industrial**

This project aims to investigate new design concepts for vessels and structure interfaces for increased reliability of exposed aquaculture operations both related to equipment, crew and fish welfare. It is expected that larger vessels will impose new requirements on the design of the floating collar and mooring system, which means that the interaction between the flexible collar and the rigid ship side will be important. Focus on the actual operations will be important in order to reduce risk and increase safety and operability.

A creative workshop focusing on equipment used in aquaculture operations was held in 2017. A vessel has been equipped with measuring equipment that supplements manual logging of operations and their limitations as described by the crew. The project engaged two summer students, one of which worked on data analysis collecting information from measurements, AIS data and meteorological data. The other student developed a tool for making advanced simulations of a variety of feed barges easily available in the SIMA workbench that is developed by SINTEF Ocean.

Tool for analysis of feed barges

Motion and mooring forces from feed barges needs more attention as aquaculture goes more exposed. An analysis tool that efficiently performs analyses of such forces has therefore been made.

The tool consists of a database for different feed barges with pre-calculated coefficients enabling easy access and setup in the SIMA workbench. SIMA[2] is a workbench for simulation and analysis of marine operations and floating systems that can be used to run MULDIF, a linear three-dimensional frequency domain potential theory numerical software, to calculate motion and wave drift forces. Viscous damping in roll and pitch is estimated and used as input to MULDIF calculations.

In SIMA, the user specifies dimension and mass properties of the feed barge to be analysed. Based on these values, the tool finds the pre-calculated set-up file from the database that provides the closest match with the input values. The SIMA set-up files contains a user interface for setting environmental conditions and define parameters for the mooring system. When the analysis is conducted, it contains a pre-defined post processor to extract and visualise selected results from the analysis.

[2] https://www.sintef.no/en/software/sima/

Simulation of coupled fish cage and well boat

A better understanding of forces between vessels and structure is needed as aquaculture sites are getting more exposed to wind, waves and current. The reliability of mooring lines and connecting lines between vessel and structure should be investigated numerically. To improve the knowledge on contact forces between vessels and structures, an example study has been performed.

A study of a well boat being moored to a fish cage has been conducted in SIMA[3] using a coupled SIMO-RIFLEX simulation to solve motion and force response of the coupled system towards regular waves and currents. RIFLEX is used to model the fish cage and mooring lines, while WAMIT is used to calculate the hydrodynamic properties of the well boat that are exported to SIMO in the SIMA workbench.

The results from the simulation will be published at the 28th International Ocean and Polar Engineering Conference (ISOPE), June 10-15, 2018 in Sapporo, Japan.

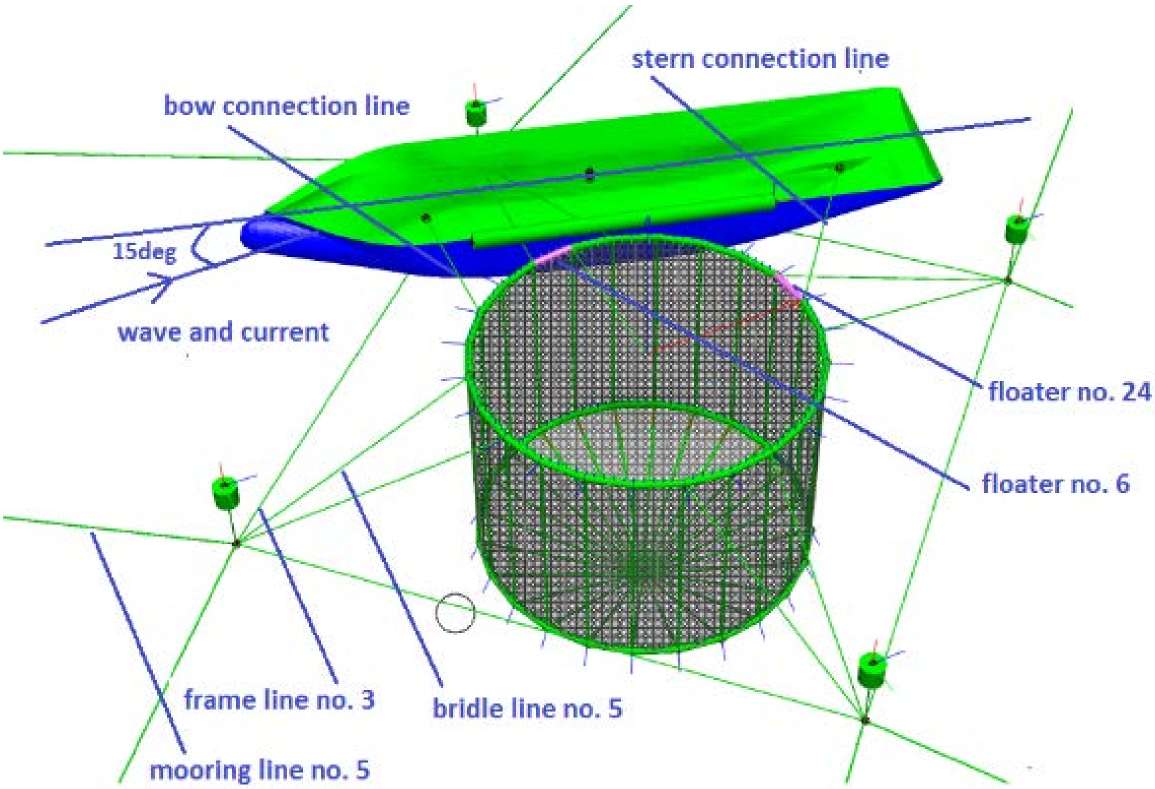


Figure 13 Simulator set-up of fish cage and well boat model in the SIMA workbench

[3] https://www.sintef.no/en/software/sima/

Feasibility

A proposed method for feasibility studies applicable for ship designers involved in the aquaculture industry is described in the project memo "P3 – Vessels – structures interaction; Feasibility study – elements and methodology."

Based on a set of critical feasibility elements, its purpose is to provide an efficient and effective way to assess and compare a given number of alternative designs during the conceptual phase of vessel development. The main value of such studies lies, not only in the possibility of assessing a vessel's performance *per se*, but also how it will perform in a real operational system.

A set of Key Performance Indicators (KPIs) necessary for the quantitative assessment and evaluation of alternative vessel designs has been proposed. With reference to figure 1, the main steps of the methodology are:

- The problem definition: description of the functional requirements for the vessel solution and its operational context.
- The creative process: develop alternative vessel and operational concepts.
- The analytical process: quantitative and qualitative evaluation of different concepts promoted throughout the process.

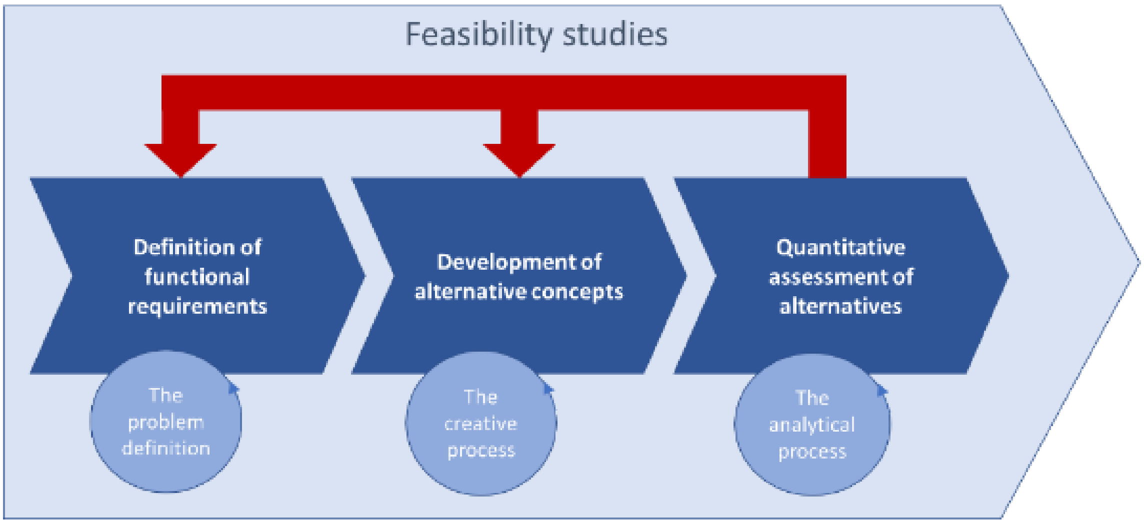


Figure 14 Functional concept assessment process (Source: derived from Norstad, et al., 2017)

Figure 15 AQS Loke is instrumented with a Kongsberg Seatex MRU, vind sensor and GPS to study motion during operations.

P4 Safety at sea – risk management and best operational practices

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
Ingunn M Holmen, SO	**SalMar, Cermaq, Marine Harvest, Anteo, Aqualine, AQS, Lerow, NTNU IMT, SINTEF Ocean, DNV GL, MacGregor, Kongsberg Maritime, Møre Maritime, Marine Design**	**Q2 2015 – Q4 2018**	**Fundamental**

There is a significant potential for increased safety in fish farming operations by implementing systematic risk management. Risk management deals with identifying, analysing, assessing and controlling occupational risk and major accident risks, through development of mitigating measures. The project aims to develop good practices for safety and risk management during both complex and daily work operations at fish farms, as well as to suggest safety measures (barriers) to be implemented.

Previous work

The fish farming industry is the second most risk-exposed workplace in Norway regarding occupational accidents. Escape of farmed fish is another challenge. A study conducted within a previous project, Sustainfarmex, showed that today's farms already operate at the safety limit of available technology and management systems. Adverse weather conditions, suboptimal human-technology interaction and several organizational aspects are known risk factors.

Previous research has identified that certain service operations are especially hazardous regarding occupational accident risk and escape of fish (e.g. work on moorings, coupling plates and the weight system). Accident analyses reveal a lack of knowledge of risk factors during aquaculture operations. To improve the safety level at workplaces, the operators need to be aware of the safety challenges in their working environment, and safe work procedures should be well implemented. A practical approach to risk assessments based on preliminary hazard analysis was therefore suggested. This approach has been developed in cooperation with the aquaculture industry and was tested in a series of workshops. This approach to risk assessments of fish farm operations showed to ensure good involvement of the operators, as well as an increased understanding of the operational risks.

Furthermore, analyses of accidents and interviews with operational managers show that the success of many operations is dependent on the competence and abilities of individuals. This is the background for prioritising a work package about competence requirements in 2017.

Competence requirements for exposed aquaculture operators

There is a need in the aquaculture industry for specific training and competence requirements as a supplement to the regulatory qualification requirements. Causal analyses of past fish escape incidents and occupational accidents in the aquaculture industry, show that "inadequate training" has been identified as a contributing factor. Adequate training is therefore an important safety factor, and the knowledge and skills of the workers may be decisive for the operational safety.

A mapping of current competence requirements within the fish farming industry was conducted based on job descriptions. The purpose was to identify requirements considered important for safe execution of work tasks at fish farms, and to identify both well-defined and lacking areas of expertise within the industry. The results show that many of the job descriptions included in the study did not include specific requirements for formal education or experience, except for one company which state that experience from aquaculture is desirable. Most companies describe the responsibilities of the employee, in which safety factors relating to personnel, equipment and the environment are mentioned. The job descriptions for skippers emphasize that they are responsible for the crew's training and skills. In some work procedures it is pointed out that the operators have the responsibility to stop work operations for safety reasons. It is also referred to mandatory requirements and regulations, such as compliance with the Regulations on safety management for small cargo ships, passenger ships and fishing vessels, etc. Section 4, Ship Safety Act § 19, MLC 2006 and the Regulations on safety management system for Norwegian ships and mobile units.

Furthermore, relevant laws and regulations related to training and competence for personnel at fish farms and on board vessels has been reviewed. This review has included the Working Environment Act, the Ship Safety Act, the Aquaculture Act and the associated regulations. The regulations include requirements for employee competence as well as requirements for employers regarding training and organizational responsibility. The legal framework related to training and competence is extensive, but also overlapping. At present, the Norwegian Maritime Directorate is working on an amendment of the Regulations for qualifications and certification of seafarers, in which two new competence certificates (D6 & D7) for aquaculture vessel operators will be included.

A workshop was held in October 2017 on training and competence requirements in aquaculture operations. The aim was to collect input to a list of necessary competence and training requirements for fish farm operators at exposed sites. A total of 16 operators and managers from the EXPOSED partners participated. During the work sessions, the participants exchanged experience with their present systems and training procedures. The following topics were discussed:

- Non-conformity reporting and how the reports can be used for learning.
- Quality management systems with a competence module to document employee training and formal education.
- Knowledge transfer (theory vs. practice).
- The importance of equipment-specific training (by manufacturer/technology supplier).
- Certification courses (HSE, crane etc).
- Planning and risk assessments (including safe job-analysis).
- Co-determination and cooperation - Safe working practices.
- Certification requirements (e.g ASC, GlobalGAP) vs. regulatory requirements.

There were group sessions related to competence requirements for today's operations, as well as for future exposed fish farming. The following work operations were used as examples: tightening of moorings, work on coupling plates and crane operations/heavy lifting. The input from participants covered formal requirements, as well as company-based requirements that are stricter than the formal regulations. One example is that all companies require certified training for crane operators. Several companies also require IMO50 safety course for crews on vessels.

The work on competence requirements will be continued in 2018, aiming to develop recommended competence requirements for aquaculture operators.

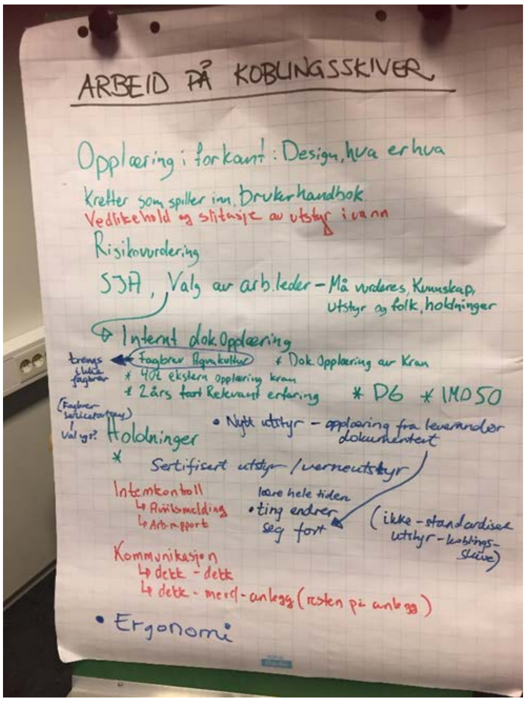


Figure 16 Workshop results - suggestions to competence requirements for the operation "work on coupling plates".

Safer operations and workplaces in fish farming (associated project)

Increased knowledge regarding health, safety and work environment at fish farms is the main objective of this project. Research areas include workers' perceptions of their work environment, safety management and organizational factors that influence safety as well as the role of design in creating a safe and healthy work environment. This provides valuable insight that may help reduce occupational risk in the industry.

Two research reports have been published from the project. Thorvaldsen et al. (2017) presents findings from a survey amongst workers in the fish farming industry. Findings show that musculoskeletal problems and occupational accidents are the main causes for work-related sick leave and health worries. Questions related to workers' perception of safety climate show several positive findings, but there are also some challenges related to sufficient manning, maintenance and putting safety first.

The second report (Kongsvik et al. 2018) explores safety management in fish farming. Overall, management and staff express a positive development in the companies' safety work in recent years. There are however, areas that need improvement such as sufficient manning, working hours and resources.

International experts will participate as scientific advisors and four master students have based their thesis on research questions from this project. An industry reference group has been established to ensure industry relevance and communication with key users.

References:

- Kongsvik T, Holmen IM, Rasmussen M, Størkersen KV, Thorvaldsen T (2018). Sikkerhetsstyring i havbruk: En spørreskjemaundersøkelse blant ledelse og stabspersonell. Trondheim: NTNU Samfunnsforskning, Studio Apertura.
- Thorvaldsen T, Holmen IM, Kongsvik T (2017). HMS-undersøkelsen i havbruk 2016. Trondheim: SINTEF Rapport OC2017 A-113

Safer operations and workplaces in **fish farming**

2016-2018 Research based in HAVBRUK2

Host and partners: **SINTEF Ocean**, SINTEF Technology and Society, NTNU Social Research, Studio Apertura

Project manager: Trine Thorvaldsen, SO

Figure 17 Maintenance work on mooring line. Photo: SINTEF Ocean (with permission from Cermaq Norway)

P5 Fish behaviour and welfare

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
Ole Folkedal, IMR	**IMR, NTNU ITK, SINTEF Ocean, Cermaq, SALMAR, Marine Harvest, Kongsberg Maritime Subsea, Aqualine, AQS, Lerow**	**Q2 2015 – Q2 2018**	**Fundamental**

Success in aquaculture operations depends on knowledge of fish physiological and behavioural limitations and opportunities, both for individual fish and the vast group sizes of farmed salmon. In exposed farming, water current strength and waves are the main concerns, and understanding fish coping ability and strategies towards these factors is the main aim of Project 5.

At the IMR, novel methodology for investigating current tolerance in individual and groups of salmon have been successfully implemented; a large swim tunnel system for swimming of both small and large individual fish and fish groups (Remen et al., 2016), and an experimental push cage system for testing of current tolerance in commercially relevant group sizes (Hvas et al., 2017a). So far, a range of experimental studies as mainly conducted in swim tunnels, has gained highly relevant knowledge for water current tolerance of salmon, as well as cleaner fish, under different environmental and physiological conditions.

Detailed knowledge of individual fish physiology and behaviour is key for understanding the coping mechanisms which exist within the natural individual variation in fish groups, and how group behaviour is driven. This especially applies to observations in a realistic farm setting, where individual fish tags allow recording of detailed information. The research done by NTNU, Department of Engineering Cybernetics, is focused on developing new acoustic transmitter tags and other technologies related to telemetry that may be key enablers for answering the biological questions towards exposed farming under commercial conditions. Solutions for new communications standards (*The Internet of fish*), and *Doppler shift* as a proxy for individual fish swimming speed are being investigated.

Swim tunnel experiments

In swim tunnel experiments, multiple aspects of fish physiology (energetics, biomechanics) and behaviour can be precisely observed under forced swimming by current speed manipulation. Measurement of oxygen consumption rates allows calculations of fish metabolism (e.g. scope for activity), and visual (camera) observations how current strength relates to behaviours of e.g. tail beat frequency or gait transitions signalling anaerobic activity. We use a large tunnel (2,5 to 5 m long) for allowing relevant behaviour in large salmon and groups of fish, and for smaller fish such as cleaner species, a small tunnel (60 cm long) to allow for measurement of oxygen consumption rates relative to their low biomass. The critical swimming speed (*Ucrit*) of fish is measured by gradual current speed increment (15-30 min intervals) until fatigue, while *sustained swimming* provides an estimate of aerobic swimming capacity over hours. Both are scientific standards that we use for estimating the effects of the external (e.g. water quality) and the internal (e.g. size, health status) environment for fish both during resting and activity. In P5, a range of relevant parameters have been tested for Atlantic salmon.

The Ucrit is naturally linked with **fish size**, where e.g. smolts were found to swim at 4 body lengths per s (~80 cm s^{-1}), while larger post-smolt (~1750 g) swam at maximum 2 body lengths per s (~100 cm s^{-1}) (Remen et al., 2016). **Temperature** dictates the metabolic rate in fish, and is thus significant for their scope of activity (how much they can mobilize), which is very important knowledge towards water current tolerance. Ucrit-testing of post-smolt (~450 g) acclimated to temperatures throughout the species temperature niche (3 to 23°C), revealed that salmon maintain a relatively high scope for activity at extreme acclimated temperature (23°C), whilst the critical swimming speed peaked at 18°C (93 cm s^{-1}), and decreased significantly at the extreme temperatures to 75 and 85 cm s^{-1} at 3 and 23°C (Hvas et al., 2017b). This tells that salmon are more vulnerable for strong current at the lower end of the temperature spectrum (3°C), which often coincide with storms and strong tidal currents during the winter.

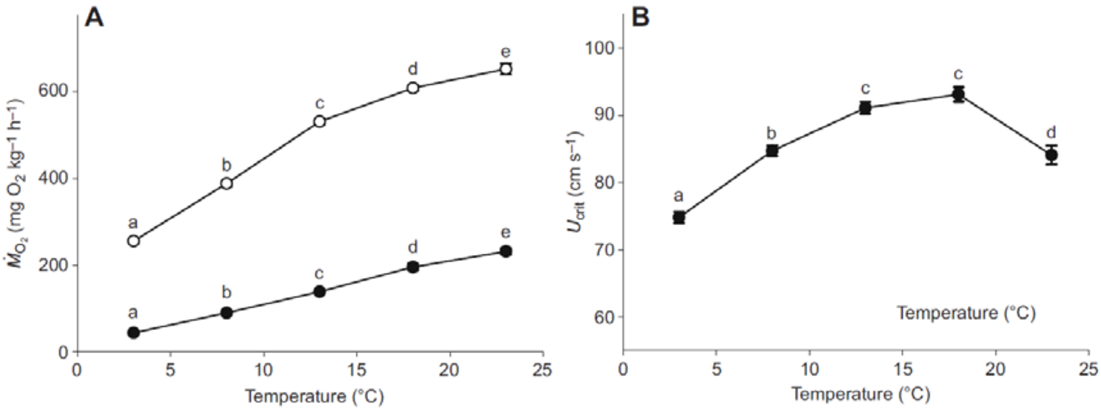


Figure 18 Standard metabolic rate (SMR) (closed circles) and active metabolic rate (AMR) (open circles), and B: critical swimming speed (Ucrit) of Atlantic salmon post-smolt acclimated to different temperatures.

Effects of water **oxygen** content show that the maximum rate of oxygen uptake was reduced in all size classes tested in moderate hypoxia (50% sat., 16°C), and consequently prolonged swimming capacity was therefore also reduced (Oldham et al., in prep). Testing Ucrit in salmon acclimated to different water **salinity** showed similar metabolic rates and swimming capacity, but an advantage in brackish water towards coping with osmoregulatory challenges, meaning that repeated swim challenges may be more difficult in full-strength seawater (Hvas et al., in review). Ectoparasites, such as the *Neoparamoeba perurans* which in salmon cause damage to the gill tissue (amoebic gill disease; **AGD**) can reduce the fish capacity for respiration and activity. While the resting metabolism of salmon heavily infected with AGD was like that of healthy salmon, the AGD fish showed only half of the scope for aerobic activity of healthy fish. For Ucrit, 2.5 body lengths s^{-1} was found in infected fish versus 3.0 body lengths s^{-1} in healthy ones, representing a dramatic reduction (Hvas et al., 2017d). **Sterile salmon** by triploidy (normal salmon is diploid) is a commercially used measure to prevent salmon escaped from farms from genetical interacting with wild salmon stocks. It has been suggested that triploids may perform better in cold water, and results from Ucrit testing at 3 and 10°C show similar performance between the ploidies at 3°C, while diploids showed higher maximum metabolic rates at 10°C and marginally higher critical swimming speeds (Nilsen & Hvas et al., in prep.).

While Ucrit reveals the maximum swimming capacity of fish over a brief time, sustained swimming in fish relies on aerobic metabolism alone and has been defined as swimming speeds that can be maintained for 200 minutes. This provides a more direct relevant measure for the aquaculture situation, and experiments with groups of post-smolts (~800 g) at 13°C was carried out in the large swim tunnel. First, the average critical swimming speed (Ucrit) was determined (97.2 cm s−1); then, sustained swimming trials were conducted in which fish were forced to swim up to 4 h at 60, 80 or 100% of the average Ucrit. In conclusion, Atlantic salmon possess the aerobic capacity for continuous high-intensity swimming of at least 80% Ucrit for several hours. This information is of high relevance for understanding Ucrit results in an applied setting, and fits well in the temporal perspective of tidal driven peaks of water current.

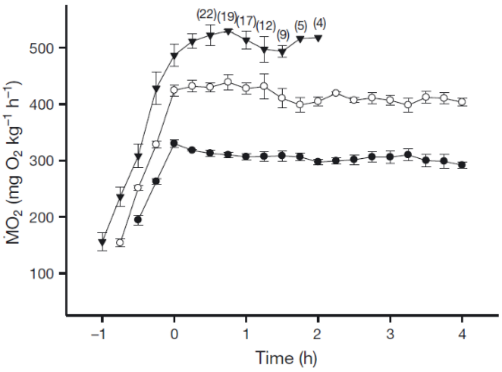


Figure 19 Oxygen consumption rates (MO2) during 4 hours of sustained swimming trial at 60% (closed circles), 80% (open circles) and 100% (triangles) of the average critical swimming speed for this batch of Atlantic salmon post-smolt corresponding to 58, 78 and 97 cm per s.

The use of **cleaner fish** in salmon sea cages, where they eat salmon sea lice of the salmon skin, is a widespread practice. Cleaner fish species are, however, of much smaller size and adapted to different niches than the salmon, and it's a timely question to ask whether these are fit for exposed environments. Ongoing work in P5 involves describing the basal biology of the lump sucker, which the later years has become the most used cleaner fish species in the salmon industry. Preliminary data from experiments conducted in a small swim tunnel and tanks show that, in contrast to the athletic and highly flexible salmon, the lump sucker has a much narrower thermal niche, lower aerobic capacity, and a weak response to acute stressors (Hvas et al., in prep). In terms of swimming capacity, it cannot cope with levels that are considered as moderate within the much wider tolerance spectrum of the salmon. The suction cup, as located on the belly of the lump sucker, seems to be used for energy saving purposes rather than as a mechanism for "anchoring" to substrate in high water current velocity. So far, we regard the lump sucker as unfit for coping with the water current in exposed farming environments. The ballan wrasse is the second most numerous cleaner fish species used in salmon sea cages, and comparative studies to the ones carried out for the lump sucker will be conducted during 2018.

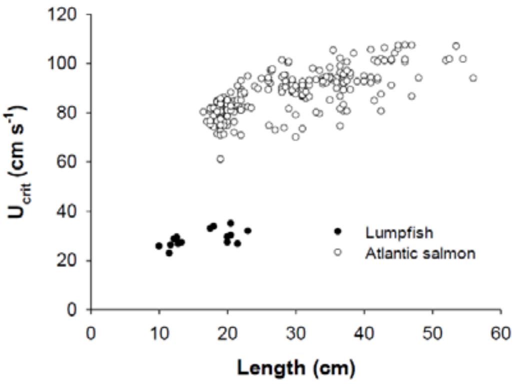


Figure 20 Comparison between critical swimming speed relative to individual fish length (cm) in lumpfish (closed circles) and Atlantic salmon post-smolt (open circles). Data from Hvas et al. (2017, in prep.).

Push cage and field studies

Using the experimental push cage (a sea cage fixated to a ship) the critical swimming speed in groups of 1500 large salmon (3.4 kg) was estimated above the levels of similar sized fish as recorded in swim tunnels, suggesting that schooling fish save energy in a similar fashion to cyclists riding in a peloton/group (Hvas et al., 2017). To further investigate this possible effect, a novel push cage design will be used during 2018, where among other factors, the impact of group size/fish density (from a few fish to crowding) on Ucrit and sustained swimming will be investigated in smolts. Other planned experimental work includes testing of individual tags (including heart rate measurement), and describing the behavioural dynamics of individual fish within salmon schools during forced swimming.

In an established cooperation between SFI Exposed and Fiskaaling (Faroes), experimental work in commercial exposed salmon farms will be carried out in 2018 and 2019 at the Faroe Islands. In this, the cage environment, including waves and water current, will be continuously logged over full sea production cycles, and be compared with fish behavioural observations by hydro acoustics (group vertical positioning) and cameras (group structure and individual swimming speed), periodical evaluation of fish physical condition (Salmon Welfare Index Model) and production data. A strong focus will be on waves, which is, at least for now, of low relevance to investigate in a lab setting. The field studies are expected to provide data of very high relevance in advising the development of exposed farming operations, as well guiding the focus in future lab experiments.

Technological development of fish tags

Individual properties of sea caged fish, such as spatial utilization and external environment (e.g. temperature and oxygen levels), internal environment (e.g. body temperature) and swimming activity (e.g. acceleration) can be measured in battery driven fish tags. Using acoustic tags, data measured by sensors within the tag is transferred wirelessly to and stored within acoustic receiver units containing hydrophones (telemetry). Simultaneously, fish position data can be calculated from the tag communication timelines with the hydrophones. Acoustic tags thereby represent a huge benefit versus internal data storage tags where the tag/fish must be retrieved after the experiment to access data. Some of the most important aspects in tag development lie in the choice of relevant sensors and developing these into proxies for quantifying fish behaviour and physiology, and how this relates to fish/tag size, communication, and battery life/energy efficiency.

In P5, a prototype module for providing fish telemetry data in real time, named the '*Internet of Fish*', is developed. The module uses radio communication and LPWAN to transmit data received from an acoustic receiver to a remote server. The remote server is running on a PC on which the telemetry data can be viewed/analysed in real time. The module is designed with a special consideration to optimising energy efficiency. The development of the module is now complete, and it is ready for deployment in sea cages.

Knowing the swimming speed of individual salmon is important for understanding behavioural strategies towards water current and whether waves affect their behavioural control in sea cages. For this purpose, the feasibility of fish speed measurement using Doppler shift is investigated. So far, the experiments in this direction has focused on investigating the frequency stability of static and moving tags.

Summary of P5

The systematic approach of developing research tools and facilities, and describing the fundamentals of salmon physiology and behaviour towards exposed aquaculture conditions, have so far provided a strong fundament for future and more applied work, as well as input to advisory processes within the SFI Exposed, the farming community in general and governmental organs. The results from P5 are especially useful towards strategic production management and for construction design that may alleviate current and wave exposure.

ECHOFEEDING (associated project)

Waste feed is a huge economic cost and source of environmental impact in salmon sea-cage farming. Appetite monitoring and feed control is key to reducing waste feed and optimizing fish growth for maximum profits. However, visual-based techniques in current use are labour-intensive, imprecise and prone to overfeeding, and becoming increasingly inadequate in larger modern cages of different designs. In this project, we will explore the technology application of an ECHOFEEDING system to autonomously monitor fish appetite and control feeding. The technology uses echo sounder transducers to monitor fish and calculate their biomass in the feeding area of a cage. When feeding is performed, it is pre-programmed to continue or stop feeding based on the amount of fish biomass levels in the feeding area. In this way, fish appetite is measured in real-time and dictates feed quantities at each meal. In contrast to visual-based appetite monitoring, the technology of ECHOFEEDING does not require continuous visual observation and can objectively quantify fish appetite. Intensive feeding over shorter intervals is a prerequisite for ECHOFEEDING, leading to longer fish residency times at lower cage depths and reduced contact with surface-dwelling infective salmon lice larvae. We will determine optimal methodology for commercial scale use of the technique, examine factors explaining fish appetite variation in caged salmon and assess the applicability of fish appetite recordings from ECHOFEEDING as an early-warning system for poor fish welfare. Technology innovation achieved in this project has the potential to substantially lower waste feed, maximize economic returns and improve fish welfare in the Norwegian salmon farming industry.

ECHOFEEDING - Echo sounder technology for appetite-led-feeding and welfare-monitoring of caged salmon

2017-2020 Research based in HAVBRUK2

Host and partners: **Institute of Marine Research**, Uni. Melbourne, Uni. Bergen, Lindem Data Acquisition AS.

Project manager: Ole Folkedal, IMR

Future Welfare (associated project)

The Future Welfare project will address key knowledge gaps related to the behaviour and welfare of farmed salmon introduced by the rapid and recent development of an array of new farming systems and locations. These new farming systems attempt to reduce long-standing and intractable environmental problems such as salmon lice infestations and the escape of farmed fish. However, new knowledge is required to assess how these new farm types impact the behaviour and welfare of salmon. Future Welfare will first develop fundamental knowledge on production environments, fish behaviour and welfare in new farming systems and locations using three case studies of existing and planned technologies (exposed traditional cages, lice-barrier skirt and snorkel cages, and submerged cages). We will generate knowledge of the adaptive capacity of fish within these new farming systems, and how this can be facilitated or encouraged for production and welfare benefit. Using results from each case study, we will adapt an existing standardized welfare assessment method to incorporate new welfare indicators and create a welfare assessment method suited for new farming systems. Finally, we will build a predictive biophysical model that integrates cage environments and fish behaviours to predict how new farming systems will affect fish behaviours and welfare. The predictive model will be made freely available to cage developers so that outcomes for fish can become central to technological design processes.

Future Welfare - Environmental requirements and welfare indicators for new cage farming locations and systems.

2017-2021 Research based in HAVBRUK

Host and partners: **SINTEF Ocean**, Institute of Marine Research, University in Bergen, University of Melbourne, Fiskaaling

Project manager: Pascal Klebert, SO

P6 Decision support systems

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
Gunnar Senneset, SO	**NTNU IDI, Anteo, Kongsberg Maritime, DNV GL**	**Q3 2015 – Q4 2018**	**Industrial**

Management and operation of modern aquaculture sites requires monitoring of biomass, environment and complex infrastructures to ensure efficient and safe production. The acquired data are used as a basis for operational decisions. As the industry is moving towards more exposed sites, it is highly likely that the need for monitoring and decision support systems will increase. Limited access for personnel in periods of rough weather will also require the possibility for remote operation of site equipment. Autonomous systems will also be increasingly important, both for resolving critical situations and for increasing the production efficiency.

Decision support tools for exposed aquaculture operations will require data from both new types of sensors as well as those currently used in the industry. As there is a wide range of methods and tools in the AI (Artificial Intelligence) and ML (Machine Learning) fields, it can also be expected that a combination of methods will be necessary to cover the main challenges regarding management and operation at exposed aquaculture sites.

The work in 2017 has focused on developing and testing a new architecture for decision support (Figure 21) developed by PhD Bjørn Magnus Mathisen. This has been done in parallel with discussions with industry partners as a basis for identifying the most important requirements for decision support in exposed operations. This work will continue in 2018, supported by increasing amounts and types of data available for further work. Challenges regarding integration of data from different sources will also be addressed.

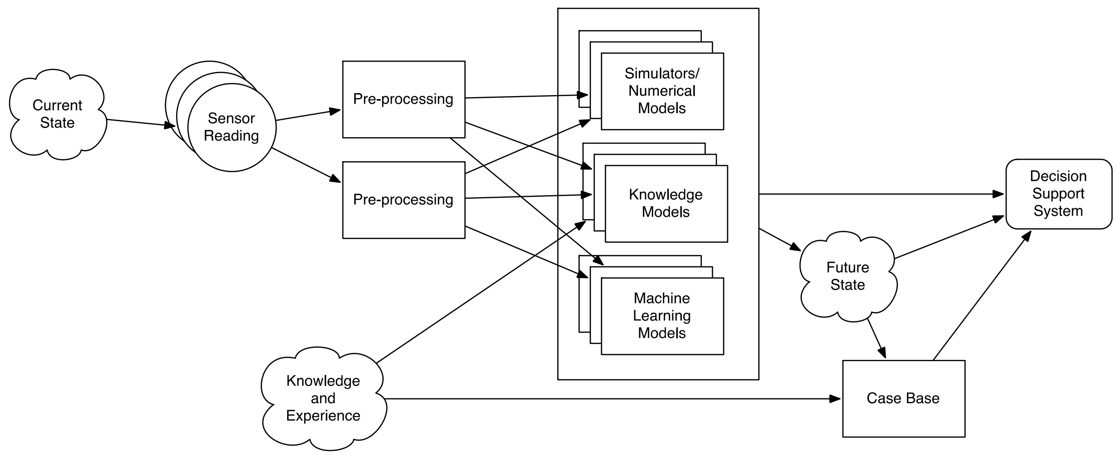


Figure 21 New architecture for decision support (source: B. M. Mathisen)

P7 Structural design of reliable offshore aquaculture structures

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
David Kristiansen, SO	**Aqualine, AQS, DNV GL, ÅF Engineering, LEROW, Kongsberg Seatex, SalMar, NTNU IMT**	**Q1 2016 – Q4 2018**	**Industrial**

This project aims to contribute with new knowledge on the physical behaviour of fish farm structures during operation at exposed locations. It will develop knowledge-based design criteria for main components of aquaculture structures for exposed locations.

Fish farming at exposed locations requires robust and reliable structures that facilitate sustainable, safe and efficient production. The cages, mooring systems and feed barges that is used by the industry today is capable of operating at the sites in present use, but how will they perform when waves and current increases beyond the current level? As wave and current exposure increases, the forces on, and the response of, the structures increases and changes. Performance of the structural components under increased exposure must be evaluated relative to the behaviour of the complete system. An essential premise for design of reliable aquaculture structures for an exposed location is an adequate description of the physical environment and corresponding representative design conditions.

The project is divided into four work packages (WP's):

1. Description of exposure
2. Numerical and physical modelling
3. Identification of critical problem areas
4. Research-based design criteria

The project work of EXPOSED P7 has in 2017 focused on the environmental description of exposed coastal sites in relation to engineering design of aquaculture structures. This work has resulted in three conference papers presented at the OMAE 2017 conference in Trondheim. The paper Lader et al. (2017) presented a classification of aquaculture sites in Norway with respect to wind-wave exposure, indicating that about 18 % of Norwegian aquaculture sites experience wind-wave conditions characterized as large and high exposure statistically at least once a year. Statistical treatment of wave measurement data from an exposed aquaculture site, as presented by Bore and Amdahl (2017), showed that it is important to consider the directional dependency of waves in the coastal zone when predicting extreme values from a joint probability distribution of significant wave height *Hs* and wave peak period *Tp*. Use of directional dependent data improves the fit to relevant statistical distributions, compared to the use of omni-directional data, and hence yields improved estimates of the extreme values. Based on statistical analysis of field measurement data of waves and current from two exposed coastal sites, Kristiansen et al. (2017) found that the procedures described in the technical standard NS 9415 for estimation of dimensioning wave and current conditions from field measurements, is insufficient. Further, approaches from ocean engineering for description of exposure at the open sea are not directly applicable for coastal aquaculture sites.

A workshop on environment description in the exposed coastal zone relevant for engineering design of aquaculture structures was held at SINTEF Ocean on October 24, with 25 participants from industry and academia. Focus was on the description of waves and current conditions in the coastal zone, based on data from field measurements and numerical simulations, including the statistical treatment of such data for prediction of extreme values for use in design. Presentations of state-of-the-art in environment mapping and description for exposed coastal sites were given by invited speakers. The presentations were followed by discussions on weaknesses and possible improvements of the present practice. Main conclusions from the discussions were that wave conditions can often be modelled adequately by careful use of sophisticated and dedicated software for wave modelling near-shore. However, the reliability of numerical results depends on the complexity of the site topography and bathymetry. Current practice for estimation of dimensioning current based on short time-series from field measurements, as described in the technical standard NS 9415, is not adequate and yields large uncertainties of the estimated extreme values.

New DNV GL Classification Rules for Offshore Fish Farming Units

Several of the new exposed fish farming concepts apply standards and regulatory practices from the maritime and offshore industry as basis for their design and construction. Given its expertise in these industries, DNV GL has observed considerable interest from stakeholders like authorities, finance institutions, insurance, owners and designers/builders for developing a classification service related to fish farming units, similar to practices applied for floating offshore units.

Responding to these initiatives, DNV GL has issued a new set of class rules for classification of offshore fish farming units/installations (DNVGL-RU-OU-0503) in July 2017. The rules focus on technical safety and seaworthiness and cover areas like load-carrying structures, stability and watertight integrity, mooring, marine-, electrical- and instrumentation systems. The rules have been well received both in Norway and internationally. Several new concepts have already been granted an "approval in principle", based on an initial design review according to the rules.

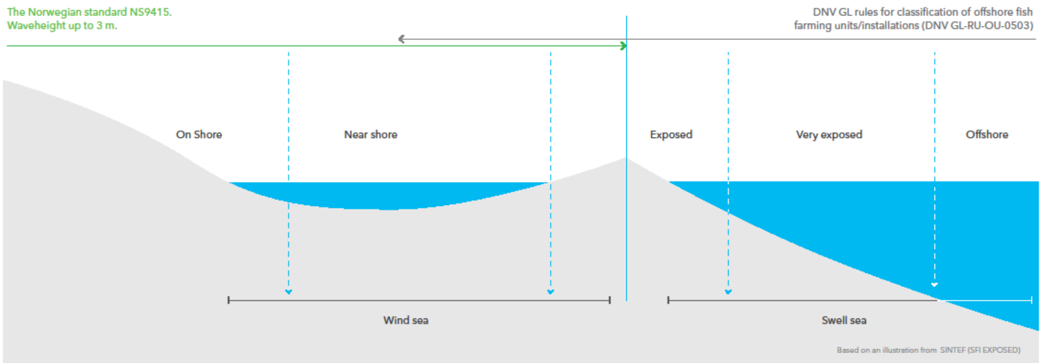


Figure 22 DNV GL Classification Rules for Offshore Fish Farming Units. (DNV GL-RU-OU-0503)

P8 EXPOSED e-Infrastructure

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
Gunnar Senneset, SO	**Cermaq Norway AS, Marine Harvest Norway AS, SalMar Farming AS, Aqualine AS, Kongsberg Seatex**	**Q3 2015 – Q4 2018**	**Industrial**

Industrial scale field experiments will constitute an important basis for developing new knowledge and technology for operations at exposed sites. Cost effective implementation and documentation of such experiments require flexible and reliable e-Infrastructure. Exposed sites operated by Cermaq Norway AS, Marine Harvest Norway AS and SalMar Farming AS are being used for field experiments.

In addition to e-Infrastructure solutions for field experiments at existing exposed sites, there is a need for new reference data series for projects within several of the research areas in EXPOSED:

- Looking further ahead: All three fish farming companies are considering 'next generation sites', and detailed data on wind, waves and currents are needed to provide design criteria for equipment and operations on such sites.
- Operational constraints: What are the limits for safe operations on todays exposed sites with respect to absolute and relative movements (accelerations, roll/pitch/yaw) on installations and vessels?

The focus on long-term data series from oceanographic buoys continued in 2017. Cermaq deployed their new buoy in November on the location Mulen (Figure 23)

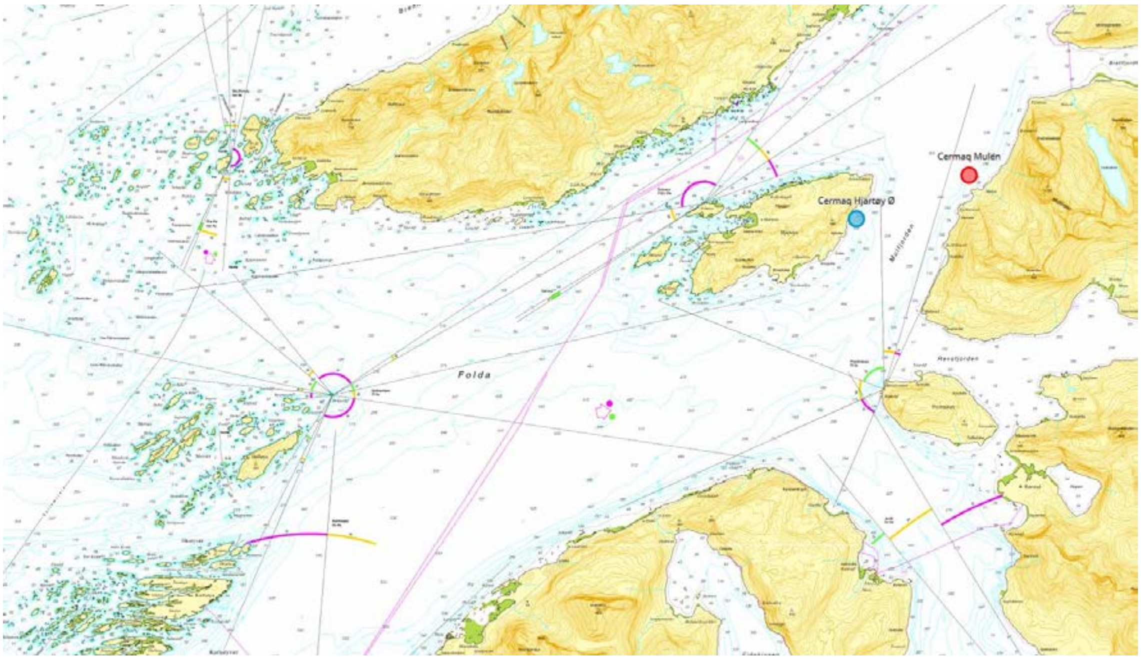


Figure 23 Cermaq site Hjartrøy (blue dot) and location of oceanographic buoy at possible new site Mulen (red dot)

SalMar Farming decided not to use the site Salatskjæra in 2017, and their Seawatch buoy will be moved to the site Hosenøyan (Figure 24). Hosenøyan is one of the most exposed sites SalMar Farming is operating in Trøndelag, and is because of that well suited for experiments which need measurements during periods of rough weather conditions. The site is situated outside the island Stokkøya in the municipality of Åfjord (see map below), and the significant wave height is estimated to be 3,6 meters. The Seawatch buoy will be in a position south-west of the site.

Buoy data are available for project partners through a web interface. Aggregated and recent graphs of the environmental conditions at the sites are published at the external web page:

http://exposedaquaculture.no/boyedata/.

In addition to the Seawatch buoy, instrument cabinets for connecting various types of sensors are installed on one of the cages which are most exposed for waves from a south-westerly direction. These cabinets will be accessible from SINTEF SeaLab through our broadband network. This ensures that automated data transfer, monitoring and remote sensor configuration is possible.

As a start for collecting long-time data series, a Kongsberg Seatex MRU (Motion Reference Unit) will be installed on cage 5 and on the feed barge.

In addition to this, an IMU (Inertial Measurement Unit) will be installed onboard in the wheelhouse of the site workboat. This will record accelerations and movements of the vessel, and also the position from a GPS receiver. Data are stored on a local computer before transfer to SINTEF SeaLab.

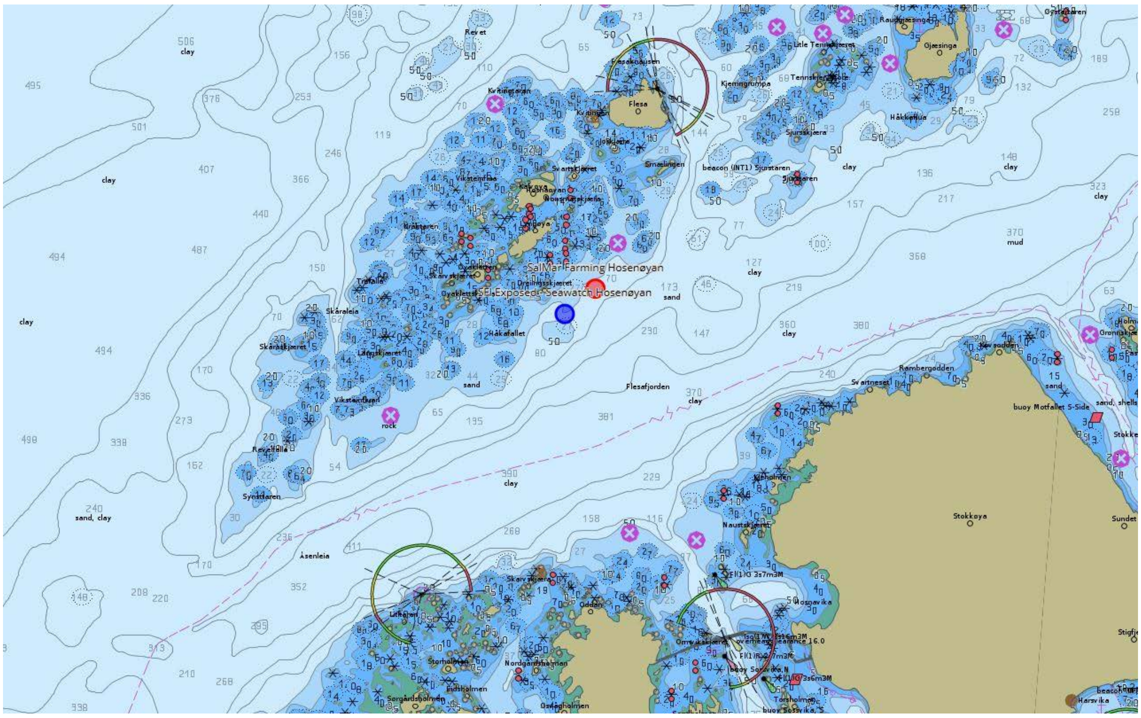


Figure 24 SalMar Farming site Hosenøyan (red dot) and oceanographic buoy (blue dot)

P9 Future Scenarios

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
Hans Bjelland, SO	**NTNU IMT**	**Q1 2017 – Q4 2017**	**Fundamental**

The pace of innovation is currently very high in the aquaculture industry. The potential for development licenses, low oil prices, high salmon prices, and a huge demand for production increase have led to many development projects, with a potential for significant investments in the years to come. In addition to the larger structures and concepts supported by the development licenses, a range of other technologies are under development, such as treatment units and closed and semi-closed systems. There is, therefore, a large uncertainty in which technological concepts that will be accepted, financed, and ultimately succeed in operation, and how the future aquaculture industry will be. There is a need to ensure that the activities of EXPOSED are adapted to the future concepts and industry structure.

This project has explored the use of scenario methods to assess possible future scenarios for the technological concepts and structure of the aquaculture industry. The centre will evaluate how these methods can be applied for future use.

P10 Governance and regulations

PROJECT MANAGER	PARTNERS INVOLVED	DURATION	TYPE OF RESEARCH
Hans Bjelland, SO	**DNV GL**	**Q1 2017 – Q4 2017**	**Fundamental**

An efficient governance and regulation of the industry will be the key to fulfilling the ambitions of EXPOSED to enable robust, safe and efficient fish farming at exposed locations. The challenges with current exposed farming operations and the new technology concepts under development highlight the needs to assess how governance and regulations could adapt, in order to create the necessary predictability for the aquaculture industry.

The aim of this project has been to study the governance and regulations of the Norwegian aquaculture industry, with focus on production at exposed locations. With its broad scope, EXPOSED is expected to provide knowledge and input that will be highly valuable to future revisions of governance and regulations.

One activity has been to identify how EXPOSED can contribute to the future revision of regulations and standards. Through an initiative by DNV GL, a collaboration has been sought with the relevant authorities: the Directorate of Fisheries, the Maritime Authority and the Labour Inspection Agency. The project leader (Centre manager) has represented EXPOSED in this work group. The purpose has been to draw attention to the regulations and standards applicable for technology and constructions in the aquaculture industry. In 2017, the Ministry of Trade, Industry and Fisheries commissioned the Norwegian Directorate of Fisheries and the Maritime Directorate to assess the regulations for the building and equipping of aquaculture constructions, as well as the HSE requirements. Representatives for the Directorate of Fisheries, Maritime Authority and Labour Inspection Agency were invited to an EXPOSED meeting in May and presented the status for this work, as well as their individual strategies and plans as regulatory bodies for the Norwegian aquaculture industry. Through this event, the EXPOSED centre provided a platform for dialogue between EXPOSED partners and authorities. The EXPOSED project decided to await the conclusions of the authorities, but will follow up the matter also in 2018.

The administration of the Norwegian aquaculture industry is divided between a number of ministries and regulatory authorities. An illustration of this can be seen in

Figure 25. The figure is a modification of an overview from the report by Robertsen et al. (2016), who analysed the regulatory system and legal framework for the aquaculture permissions. The current regulatory regime is fragmented with six ministries and three levels of government involved. In

Figure 25, two more regulatory areas important for the *operation* of the fish farms are included; the Maritime/Ship Safety and Work Environment legislation. Five regulatory bodies are auditing requirements on safety management in the aquaculture industry, which partly is overlapping (Holmen et al. 2017): Food Safety Authority - fish welfare and food safety; Maritime Authority - vessel design and safety; Directorate of Fisheries - fish farm design, construction and operation, including prevention of fish escape; Labour Inspection Authority - HSE for operators; County Administration - external environment. At present, the work environment responsibility of the service vessels below 15 meters is under the jurisdiction of the Labour Inspection Agency, while the building and construction of these vessels are under supervision of the Maritime Authority.

The applicability of existing industry and public standards has been assessed through identification of challenges in the fish farming industry which are not sufficiently covered by the present regulations. The following challenges are identified within the EXPOSED projects:

- Feed/accommodation barge
- Use of barges for e.g. de-licing
- Standard procedures for interactions between vessel and net cage/fish farm
- For exposed operations and new farm concepts, site survey becomes increasingly important

    - Method for determining dimensioning conditions
    - Methodology for analysis
    - Consistent and comparable site surveys
- Requirements for evaluation of new technology with regard to operational safety, fish escape prevention and fish welfare
- Competence requirements for operators
- Establish operational limits and guidelines to ensure the welfare of the fish

The work in P10 has formed the basis for coordinated activities in EXPOSED and associated projects that have relevance to the governance and framework conditions for the aquaculture industry. The dialogue with ministries, directorates and stakeholders on suggestions for a coordinated regulatory regime will be followed up by EXPOSED.

References:

- Holmen IM, Utne IB, Haugen S (2017). The status of risk assessments in Norwegian fish farming. In: Safety & Reliability, Theory and Applications. CRC Press.
- Robertsen R, Andreassen O, Hersoug B et al. (2016). Regelrett eller rett regel? Håndtering og praktisering av regelverket for havbruksnæringen. NOFIMA report 37/2016.

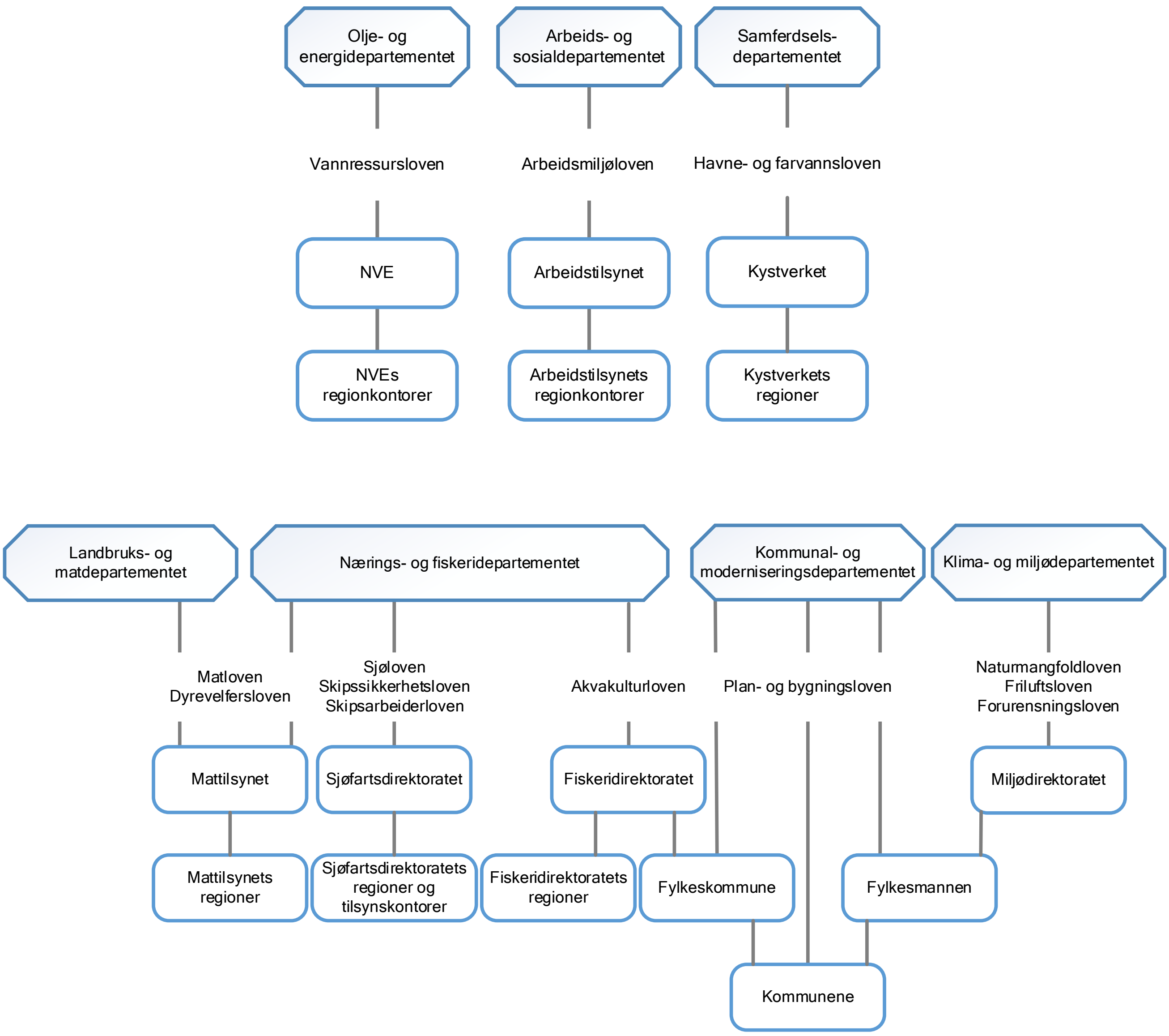


Figure 25 An overview of the administration of the Norwegian aquaculture industry. (Modification of figure in Robertsen et al. 2016).

INTERNATIONAL COOPERATION

The topic of exposed farming raises significant interest internationally.

The potential of exposed fish farming and the research of the EXPOSED centre receives attention from several regions, including Scotland, the Faroe Islands, Chile, Australia, China, South Korea and Japan.

In June, a workshop with the research organisation Fiskaaling from the Faroe Islands was held in Trondheim to discuss potential collaboration and research on fish welfare, structural integrity and environmental measurements. This has so far resulted in plans for a mutual postdoc. project and field measurements in 2018.

The research areas of the centre have been presented in various international forums to support future collaboration with other stakeholders:

- Faroese Fish Farmer Association, March, Tórshavn, Faroe Islands
- European Safety and Reliability (ESREL) 2017, June, Portoroz, Slovenia
- The gill parasite Paramoeba perurans compromises aerobic scope, swimming capacity and ion balance in Atlantic salmon - Society for Experimental Biology, June, Gothenburg, Sweden
- The International Conference on Ocean, Offshore and Arctic Engineering (OMAE), June, Trondheim Norway
- AquaNor, August, Trondheim, Norway
- Aquaculture Europe (EAS) 2017, October, Dubrovnik, Croatia
- Ocean Frontier Institute and Memorial University, St John's, NL, Canada

RECRUITMENT

Six PhDs are now hired and funded by EXPOSED, in addition to several PhDs and postdocs that are involved in associated projects.

They are invited to common activities, such as two aquaculture workshops in collaboration with NTNU AMOS. To further promote collaboration, knowledge sharing and industrial insight, EXPOSED has also partnered with other maritime research centres in a joint initiative to increase awareness and competence on innovation among PhDs and researchers.

NTNU School of innovation

Norway is a “centre of gravity” within ocean space technology. Together with international and national companies and research partners, NTNU and SINTEF have been given centre status for several leading research environments within ocean space technology. In the coming years hundreds of PhDs will perform excellent research at these centres. The challenge is to also excel in creating new products and solutions. In order to overcome this challenge, researchers will also need competence within innovation and entrepreneurship.

The main goals of the NTNU School of innovation are therefore to

1. Create a culture for innovation
2. Strengthen the awareness and competence on innovation
3. Contribute to increased commercialization of research results

Xue Yang (Post Doc) – Risk management of autonomous operations and systems in aquaculture

Xue holds a PhD degree in RAMS (Reliability Availability maintainability and Safety) from NTNU. The title of her PhD dissertation is “Decision-oriented Operational Risk Assessment, contributions to the understanding of operational risk in the oil and gas industry”. Xue is funded by the associated project «Reducing risk in aquaculture» managed by Professor Ingrid Bouwer Utne, NTNU, and funded by the Norwegian Research Council. Her research focuses on major accident risk identification in marine operations in the fish farms, especially the operations in exposed locations, considering the risk to personnel, risk to fish welfare, risk to environment and risk to material assets. The research will also explore the risk levels of autonomous operations and systems, and investigate operational limits. This will among other things contribute to identifying the needs for risk mitigation introduced by increased levels of autonomy in marine operations.

Kristbjörg Edda Jónsdóttir (PhD) - Dynamics of water flow and turbulence in large-scale aquaculture sea cages

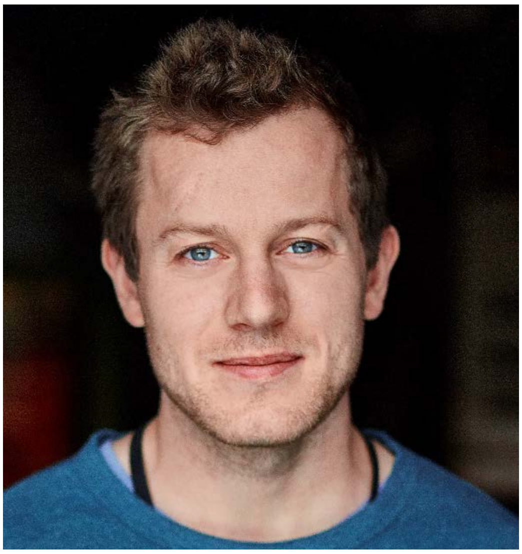
Kristbjörg has an MSc in Marine Technology from NTNU and is currently undertaking a PhD at the department of engineering cybernetics at NTNU. She is affiliated with the SINTEF RACE and BIORACER projects, and is working on establishing new theoretical and empirical knowledge related to the dynamics of water flow and turbulence inside large-scale aquaculture sea cages. To achieve this, the work will include both mathematical modelling and experimental work carried out at SINTEF's test site (SINTEF ACE) with large-scale sea cages.

Stefan Arenfeldt Vilsen (PhD) – Method for Real-Time Hybrid Model Testing of Ocean Structures

Stefan holds a master degree in Civil Engineering from Aalborg University in Denmark, with specialisation in nonlinear drift loads on floating structures.

During his PhD studies (2014-2018), Stefan has contributed to the development of "Real-Time Hybrid Model testing" for combining classical hydrodynamic model-scale testing with numerical simulations in real-time. The focus of the PhD has been developing methods for experimentally testing aquaculture structures in exposed deep-water locations, through combining simulation of moorings and riggings with experimental testing of floating structures.

Stefan's PhD is funded by SINTEF Ocean, as part of the support for the centre of excellence NTNU AMOS, associated with the project "Intelligent Offshore Aquaculture Structures"



Waseem Hassan (PhD) - Acoustic telemetry for real-time fish performance monitoring

Waseem did his bachelors in electronics engineering from NUST, Pakistan. He was awarded Erasmus Mundus scholarship for his master studies. He did his masters in embedded systems from NTNU, Norway and TU Kaiserslautern, Germany.

He joined SFI EXPOSED in December 2016 as a PhD student. His main focus is to research new techniques to monitor individual fish performance in real time. During his PhD, he will investigate the development of new types of acoustic tags, associated embedded systems and underwater acoustic communication protocols for fish telemetry.

COMMUNICATION AND DISSEMINATION ACTIVITIES

As a Centre for Research based Innovation, EXPOSED has a responsibility to disseminate research results to the public, as well as a need for effective communication internally between partners and activities.

To support cross-disciplinary innovation and good communication within the centre, the centre has arranged a two-day EXPOSED Days in the spring and a one-day EXPOSED Day in the autumn. Such events will be arranged yearly, in addition to PhD/post-doc workshops and more targeted project related meetings. The EXPOSED Days serve as a meeting place for innovation, presentation of results, and exchange of ideas and creation of new projects.

Figure 26 Exposed days in May 2017.

Main communication channels with the public is through:

- A Norwegian facebook-page (https://www.facebook.com/eksponert) is used to share relevant news.
- Participation and presentation at international (see above) and national conferences and other fora. The centre has been invited to present at a number of national events.
- Scientific, trade and popular science articles published in relevant channels (See below).
- A web-page (http://exposedaquaculture.no/) has been established to present information about the centre to both internal and external target groups.

Figure 27 The EXPOSED web page

Figure 28 PhD/Post doc. workshop on aquaculture technology 2017.

PUBLICATIONS

EXPOSED strives to register all dissemination activities in the Current Research Information System in Norway (CRIStin). Please see https://www.cristin.no/app/projects/show.jsf?id=536331. Scientific papers are listed below.

Journal papers

2016

Bui S, Dempster TD, Remen M, Oppedal F (2016), *Effect of ectoparasite infestation density and life-history stages on the swimming performance of Atlantic salmon Salmo salar*. Aquaculture Environment Interactions 2016 (1869-215X) Vol. 8, s. 387-395

Remen M, Solstorm F, Bui S, Klebert P, Vågseth T, Solstorm D, Hvas M, Oppedal F (2016), *Critical swimming speed in groups of Atlantic salmon Salmo salar.* Aquaculture Environment Interactions 2016: Volume 8, pages 659-664.

Rundtop P, Frank K (2016*), Experimental evaluation of hydroacoustic instruments for ROV navigation along aquaculture net pens.* Aquacultural Engineering 2016 ; Volume 74.

2017

Hvas M, Folkedal O, Imsland A, Oppedal F (2017b), *The effect of thermal acclimation on aerobic scope and critical swimming speed in Atlantic salmon* (*Salmo salar* L.). J. Exp. Biol. 220, 2757-2764.

Hvas M, Oppedal O. (2017c), *Sustained swimming capacity of Atlantic salmon.* Aquacult. Env. Interact. 9, 361-369.

Hvas M, Karlsbakk E, Mæhle S, Wright D, Oppedal F (2017d), *The gill parasite Paramoeba perurans compromises aerobic scope, swimming capacity and ion balance in Atlantic salmon.* Conservation Physiology 5. 10.1093/conphys/cox066

Hvas M, Folkedal O, Solstorm D, Vågseth T, Fosse JO, Gansel LC, Oppedal F (*2017a), Assessing swimming capacity and schooling behaviour in farmed Atlantic salmon Salmo salar with experimental push-cages,* Aquaculture, Volume 473, 20 April 2017, Pages 423-429

Mathisen B M, Aamodt A, Langseth H (2017), *Data driven case base construction for prediction of success of marine operations*. CEUR Workshop Proceedings 2017; Volum 2028. s. 104-113, NTNU

Conference papers

2016

Bjelland H, Føre M, Lader P, Kristiansen D, Holmen IM, Fredheim A, Grøtli EI, Fathi DE, Oppedal F, Utne IB, Schjølberg I (2016), *Exposed aquaculture in Norway- Technologies for robust operations in rough conditions.* Proceedings from OCEANS' 15 MTS/IEEE, Washington, USA, 19-22 October 2015.

2017

Arnesen BO, Lekkas AM and Schjølberg I (2017), *3D path following and tracking for an inspection class ROV,* In: Proc. of the 36th International Conference on Ocean, Offshore & Arctic Engineering (OMAE17), June 25-50, 2017, Trondheim, Norway.

Bore PT & Amdahl J (2017), *Determination of environmental conditions relevant for the ultimate limit state at an exposed aquaculture location*. In proceedings of the 36th Offshore Mechanics and Arctic Engineering Conference, OMAE2017-61413, June 25-50, 2017, Trondheim, Norway.

Bore PT, Amdahl J, Kristiansen D, (2017), *Modelling of Hydrodynamic Loads on Aquaculture Net Cages By a Modified Morison Model.* 7th International Conference on Computational Methods in Marine Engineering, At Nantes, France

Grøtli EI, Bjerkeng M, Rundtop P, Vagia M, Haugli FB, Transeth AA (2017), *Canvas as a design tool for autonomous operations: With application to net inspection of a sea based fish farm using an underwater vehicle*, OCEANS, Aberdeen, UK

Holmen IM, Utne IB, Haugen S (2017*), Organisational safety indicators in aquaculture – a preliminary study. Risk, Reliability and Safety: Innovating Theory and Practice:* Proceedings of ESREL 2016 (Glasgow, Scotland, 25-29 September 2016). CRC Press.

Holmen IM, Utne IB, Haugen S, Ratvik I (2017), *The status of risk assessments in Norwegian fish farming.* In: Safety & Reliability, Theory and Applications. CRC Press.

Kristiansen D, Aksnes V, Su B, Lader P and Bjelland HV (2017), *Environmental description in the design of fish farms at exposed locations*. In proceedings of the 36th Offshore Mechanics and Arctic Engineering Conference, OMAE2017-61531, June 25-50, 2017, Trondheim, Norway.

Lader P, Kristiansen D Kristiansen, Alver M, Bjelland HV & Myrhaug D (2017), *Classification of aquaculture locations in Norway with respect to wind wave exposure*. In: The 36th International Conference on Ocean, Offshore and Arctic Engineering, OMAE2017.

Mathisen BM, Aamodt A, Langseth H (2017), *Data driven case base construction for prediction of success of marine operations.* ICCBR-17 Workshop on Workshop on Case-based Reasoning and Deep Learning - CBRDL 2017; 2017-06-26 - 2017-06-26, NTNU

PERSONNEL

Key Researchers	Institution	Main research area
Hans V. Bjelland	SINTEF Ocean	Decision support systems and aquaculture operations
David Kristiansen	SINTEF Ocean	Aquaculture structures
Ingunn Marie Holmen	SINTEF Ocean	Safety and risk management
Trine Thorvaldsen	SINTEF Ocean	Safety and risk management
Andreas M. Lien	SINTEF Ocean	Vessel design and aquaculture operations
Leif Magne Sunde	SINTEF Ocean	Aquaculture operations
Per Rundtop	SINTEF Ocean	Autonomous systems
Pål Lader	SINTEF Ocean/NTNU	Aquaculture structures
Heidi Moe Føre	SINTEF Ocean	Material science
Per Christian Endresen	SINTEF Ocean	Aquaculture structures
Arne Fredheim	SINTEF Ocean	Aquaculture structures
Gunnar Senneset	SINTEF Ocean	Field measurements and infrastructure
Martin Føre	SINTEF Ocean	Telemetry and biological modelling
Dariusz Fathi	SINTEF Ocean	Vessel design
Ørjan Selvik	SINTEF Ocean	Vessel design
Vegard Ø. Aksnes	SINTEF Ocean	Aquaculture structures
Frode Oppedal	Institute of marine research	Fish behaviour and welfare
Ole Folkedal	Institute of marine research	Fish behaviour and welfare
Esten Ingar Grøtli	SINTEF Digital	Autonomous systems
Trine Kirkhus	SINTEF Digital	Optical Measurement Systems and Data Analysis
Jørgen Amdal	NTNU, Department of Marine Technology	Marine structures
Trygve Kristiansen	NTNU, Department of Marine Technology	Marine structures
Ingrid B. Utne	NTNU, Department of Marine Technology	System safety engineering, risk assessment, and maintenance management of marine systems
Stein Haugen	NTNU, Department of Marine Technology	Risk monitoring and analysis
Agnar Aamodt	NTNU, Department of Computer and Information Science	Intelligent systems and decision support
Kerstin Bach	NTNU, Department of Computer and Information Science	Intelligent systems and decision support
Helge Langseth	NTNU, Department of Computer and Information Science	Intelligent systems and decision support
Jo Arve Alfredsen	NTNU, Department of Engineering Cybernetics	Telemetry and biological modelling

PhD students with financial support from the Centre budget

Name	Nationality	Period	Sex (M/F)	Topic
Bjørn Magnus Mathisen	Norway	Q3 2015 - Q3 2019	M	Monitoring and operational decision support.
Pål Takle Bore	Norway	Q1 2015 - Q3 2018	M	Intelligent Aquaculture Structures
Ingunn Marie Holmen	Norway	Q1 2016 - Q4 2019	F	Safety and risk management
Bent Arnesen	Norway	Q3 2016 - Q3 2019	M	Remotely controlled and automated underwater vehicles
Malthe Hvas	Denmark	Q2 2016 - Q2 2019	M	Physiology and behaviour of salmon in strong water currents
Waseem Hassan	Pakistan	Q4 2016 - Q4 2020	M	Acoustic fish telemetry for real-time fish performance monitoring in aquaculture

PhD students working on projects with financial support from other sources

Name	Nationality	Period	Sex (M/F)	Funding	Topic
Kristbjörg Edda Jónsdóttir	Norway	Q3 2016 - Q3 2019	F	Strategic research project of SINTEF Ocean	Dynamics of water flow and turbulence in large-scale aquaculture sea cages
Stian Sandøy	Norway	Q3 2016 - Q3 2019	M	Reducing risk in aquaculture – improving operational efficiency, safety and sustainability. Funded by Havbruk2 in the Norwegian Research Council	Sensor fusion for autonomoous underwater inspection of aquaculture structures
Yugao Shen	China	Q3 2013 - Q3 2016		NTNU AMOS - Centre for Autonomous Marine Operations and Systems	Limiting operational conditions for a well boat
Stefan A. Vilsen	Denmark	Q1 2014 - Q1 2018		NTNU AMOS - Centre for Autonomous Marine Operations and Systems	Hybrid model testing of marine systems

Postdoc. researchers working on projects with financial support from other sources

Name	Nationality	Period	Sex (M/F)	Funding	Topic
Xue Yang	China	Q2 2017 - Q1 2019	F	Reducing risk in aquaculture – improving operational efficiency, safety and sustainability	Operational risk assessment

Master students

Name	Sex (M/F)	Period	Affiliation	Topic
Lene Erdal	F	Q1-2 2016	Industrial Economics and Technology Management, NTNU	Shared Value Creation in an Industry Context - Assessing How Governmental Policies Can Contribute to Increased Corporate Sustainability in the Norwegian Aquaculture Industry
Marianne Wethe Koch	F			
Fredrik Lindahl Roppestad	M	Q1-2 2016	Department of Computer Science, NTNU	Decision support for predictive maintenance of exposed aquaculture structures
Niklas Bae Pedersen	M			
Helene Nordtvedt	F	Q2 2016	Department of Production and Quality Engineering, NTNU	Development of a Risk Model for Fish Farming Operations
Alexander Wallem Berge	M	Q1-2 2017	Department of Marine Technology, NTNU	Fleet Scheduling of Service Vessels used in a more exposed Norwegian Aquaculture Industry
Henrik Theodor Ramm	M			
Marius Gyberg Haugland	M	Q1-2 2017	Department of Marine Technology, NTNU	Use of Clusters in a Route Generation Heuristic for Distribution of Fish Feed
Sondre Thygesen	M			
Simen Aleksander Haaland	M	Q1-2 2017	Department of Marine Technology, NTNU	Semi-closed containment systems in Atlantic salmon production Comparative analysis of production Strategies
Jens Kristian Hole	M	Q1-2 2017	Department of Marine Technology, NTNU	Risikobasert design av fartøy og merde for eksponert havbruk
Hanne Hornsletten	F	Q2-3 2017	Department of Marine Technology, NTNU	Optimization Model Aimed for the Aquaculture Industry for Fleet Composition and Routing of Wellboats
Henrik Håkonsen	M	Q1-2 2017	Department of Marine Technology	Emergency Preparedness and Response in Aquaculture
Marte Tuverud Kamphuse	F	Q1-2 2017	Department of Marine Technology, NTNU	Modeling of Seaborne Transport of Fresh Salmon. Inventory Routing with Continuous Time Formulation for a Perishable Product
Runar Stemland	M	Q1-2 2017	Department of Marine Technology, NTNU	Assessment of Service Vessel Operability In Exposed Aquaculture. An exploratory approach combining vessel response and discrete-event simulation

Ole-Johan Nekstad	M	Q2-3 2017	Department of Marine Technology, NTNU	Modularization of Aquaculture Service Vessels - An Approach for the Implementation of Operational Flexibility
Erik Andreas Næstvold	M	Q1-2 2017	Department of Marine Technology, NTNU	Simuleringsmodell som beslutningsstøtte for valg av tiltak mot lakselus på lokalitetsnivå
Adrian Stenvik	M	Q1-2 2017	Department of Marine Technology, NTNU	Fleet Size and Mix in the Norwegian Aquaculture Sector. A stochastic fleet renewal problem with an uncertain future
Vetle Skavraker Evju	M	Q1-2 2017	Department of Marine Technology, NTNU	Competitiveness in construction of offshore fish farms Assessment of cost and strategic aspects
Ronja Eide Lilienthal	F	Q1-2 2017	Department of Marine Technology, NTNU	Discrete-Event Simulation of a Multimodal Downstream Supply Chain for Future Norwegian Aquaculture
Ragni Rørtveit	F			
Odin Dybsland	M	Q1-2 2017	Department of Marine Technology	Risikostyringsverktøy for oppdrettsnæringen
Solveig Sæbø	F	Q1-2 2017	Faculty for science and technology, UiT	Integrering av ytre miljørisiko i HMS-arbeidet - En casestudie av et fiskeoppdrettselskap
Erling Nilsen	M	Q3 2017 – Q3 2018	University of Agder	Swimming capasity of triploid salmon
David Williams	M	Q3 2016 – Q2 2017	Department of Marine Technology, NTNU	Extreme loads on a feeding barge

Figure 29 EXPOSED Days in May 2017.

STATEMENT OF ACCOUNTS

Name	Funding		Cost
The Research Council	12 045	(42 %)	-
The Host Institution (SINTEF Ocean)	1 157	(4 %)	19 320
Research Partners*	3 688	(13%)	9 081
Enterprise partners**	11 642	41 %)	-
Public partners	-	-	-
Equipment	-	-	140
Total	**28 542**		**28 542**

(All figures in 1000 NOK)

* IMR, SINTEF Digital, NTNU IMT, NTNU IDI, NTNU ITK

** Marine Harvest, Cermaq, SalMar, Kongsberg Seatex, Kongsberg Maritime Subsea, Kongsberg Maritime, Aqualine, Møre Maritime, ÅF, Anteo, Argus Remote Systems, Lerow, AQS, Marine Design, DNV GL and MacGregor Norway

sfi = Centre for Research-based Innovation

The Research Council of Norway

EXPOSED

AQUACULTURE OPERATIONS

CENTRE FOR RESEARCH-BASED INNOVATION

SINTEF Ocean · Marine Harvest Norway · Cermaq Norway · SalMar Farming · AQS Kongsberg Maritime · Aqualine · Marine Design · Lerow · ÅF Engineering · Møre Maritime Argus Remote Systems · DNV GL · SINTEF Digital · Institute of Marine Research Anteo · Norwegian University of Science and Technology · MacGregor Norway

exposedaquaculture.no